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MEMOIRS

OF THE

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Volume XVI

NATIONAL ACADEMY OF SCIENCES

OF THE

MEMOIRS

MAGDALENA BAY IN 1906, SHOWING VILLAGE ON SHORE OF MAN-O'-WAR COVE, MAGDALENA ISLAND, WHERE SHIPS USUALLY ANCHOR.

The two large buildings are the headquarters (right) and warehouse (left) of the Chartered Company of Lower California, erected during height of the orchilla industry. The entrance to the bay lies beyond the first point and between it and the northern end of Santa Margarita Island shown in the distance.

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Volume XVI.
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LOWER CALIFORNIA AND ITS NATURAL RESOURCES.

BY

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CHIEF, BUREAU OF BIOLOGICAL SURVEY, UNITED STATES DEPARTMENT OF AGRICULTURE.

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LOWER CALIFORNIA AND ITS NATURAL RESOURCES.

(With 35 plates.)

By EDWARD W. NELSON,
Chief, Bureau of Biological Survey, U. S. Department of Agriculture.

GENERAL INFORMATION.[1]

The present account of Lower California has been prepared as one of the results of an expedition from the Bureau of Biological Survey of the United States Department of Agriculture, which traversed the entire peninsula during 1905 and 1906 under my direction, assisted by Mr. E. A. Goldman.

The difficulty of securing definite information concerning Lower California and the erroneous character of many published statements concerning it have led me to include, in addition to a brief account of our journey, short chapters on various phases of its physical character, resources, and other subjects, with a bibliography.

A variety of causes has resulted in long delaying the appearance of this report. Its publication at the present time, however, appears opportune in view of recently awakened interest in the peninsula. Some of the changed conditions or new developments which have occurred since the time of the expedition are noted in their proper places.[1]

Lower California was discovered by Cortez in 1535, soon after he completed the conquest of the Mexican mainland. Efforts were at once made to colonize the new territory, which was supposed to be an island, and the first colony was located where La Paz now stands.

At the time of its discovery, Lower California was inhabited by Indians in a most primitive state of development. According to the early records these natives numbered about 25,000 individuals, which were grouped under three tribal designations, distributed as follows: The Pericues were said to have occupied the peninsula from Cape San Lucas to about 24° north latitude, including Ceralvo, Espiritu Santo, and San Jose Islands. The Guaicuras were said to have occupied the middle region from near 24° to near 26° north latitude and Cedros Island. The Cochimies occupied the northern section from 26° to 33° of latitude, including the adjacent islands along the western coast. From our present knowledge it is evident that this classification of the Indians was extremely imperfect, particularly as referring to those of the northern section, in which most of the surviving native population now lives. It is known that survivors of several tribes still exist in northern Lower California, of which perhaps the Cocopahs about the delta of the Colorado are the most notable. The Indian population of the peninsula has decreased until only a few hundred now remain, and some of the tribes have no doubt disappeared forever.

Information concerning Indian population in Lower California at various periods.

Locality.	Year.	Number.	Year.	Number.
San Francisco Xavier Mission	1768	485	1857	56
Guadalupe Mission	1768	520	1857	11
La Virgin de los Dolores Mission	1768	450	1857	6
San Luis Gonzaga Mission	1768	310	1857	20
Santa Gertrudis Mission	1768	1,000	1857	4
San Borja Mission	1768	1,500	1857	3
Santa Maria Mission	1768	330	1857	0
San Fernando Mission	1710	530	1857	3
San Pedro Martir Mission	1796	420	1857	1

[1] The chapter on general information includes data received to the end of the year 1912.

As already stated, at the time of its discovery the Indian population of Lower California was estimated to number about 25,000. In 1857 the number was thought to be about 2,500. In 1919 it is reported that there remain about 600 in the northern district, many of whom, no doubt, are of mixed blood. Few of these remain at the old missions, most of them being in scattered villages and rancherias. At Santa Catarina Mission they number 45, as against 180 reported in 1898. About 1914 the inhabitants in the Indian village La Huerta, at the base of the Juarez Mountains, numbered 75. This is the largest number of Indians in any village I know in this region. They have practically disappeared from the southern district.

In connection with the Indian population of the peninsula it is interesting to note that a considerable number of Yaquis from Sonora have for many years worked in the mines along the gulf coast of the peninsula. About 1909 a colony of these Indians, who had been working at the placer mines at Miramar, settled just above the village of El Rosario, on the west coast, where they developed water and are cultivating a small area of land. This colony now numbers about 30 individuals.

Between the hostility of the Indians and the severe desert conditions of the new land the early colonists suffered great dangers and privations. In the face of extreme dangers and hardships some of the missionaries, notably Padres Kino, Ugarte, and Salvatierra, animated by a wonderful spirit of self-sacrificing heroism, gradually explored the entire peninsula and established missions at the main watering places throughout its length. Nearly four centuries have passed since the discovery and all but two or three of the numerous missions, reared with such labor, are in ruins, and the sites of many of them are abandoned, while all but a handful of the Indian tribes which once roamed the deserts have disappeared.

The desert character of the peninsula, combined with political handicaps, have continued to hold back its settlement and development by Europeans. As a result, notwithstanding its close proximity to California, readily available information concerning the country and its natural resources has been scanty and frequently misleading. The main sources of detailed information concerning it in the United States have been the reports of various American naturalists, including zoologists, botanists, and geologists, who from time to time have explored parts of the peninsula.

Two Mexican Government reports, however, contain much detailed information on the geology and resources. The first is by Joaquin Ramos concerning an expedition to the middle parts of the peninsula in 1884. The other is a joint report of a commission sent by the Instituto Geologico to the northern district in 1911. The account by Venegas of the early exploration and occupation of the peninsula has been translated into English and is full of interest.

Mines.

During the last 50 years many prospectors, mainly Americans, have wandered over the country, and a few mining camps, usually of small size, have been established. Prospects have been found on the peninsula showing that a considerable variety of minerals exist. These include gold, silver, copper, lead, zinc, iron, manganese, mica, salt, sulphur, and magnesite, in addition to turquoise, tourmaline, onyx, and marble.

The largest existing mining camp is that of Santa Rosalia, on the middle of the gulf coast, where a French company has developed El Boleo, one of the larger copper mines of the world, which in 1905 was said to support a population of several thousand people. The largest silver mine on the peninsula, El Triunfo, located south of La Paz and worked by an American company, once supported a mining camp of considerable size. More recently it declined, until in 1905 only a small force was employed.

At the time of our visit, onyx was being mined by an American company at the onyx mine on the east side of Llano de los Buenos Aires, whence it was hauled by wagon to Santa Catarina Landing on the west coast and shipped to San Diego. El Alamo, a gold and silver mine southeast of Ensenada, once of some importance, was being worked on a small scale at the time of our visit, but I learn that in 1912 the work ceased and now the camp is practically deserted.

Mines carrying lead, zinc, and silver are now being worked on a considerable scale on the east side of the Pinta Mountains near the mouth of the Colorado River. During the war small

quantities of copper ore were mined and shipped from prospects near Salada, San Quintin, Sausalito, San Fernando, Santa Catarina, San Julio, and at San Jose, about 25 miles south of Ensenada.

Many small mines and prospects have been worked from time to time in all parts of the peninsula, including the dry placer mines at Santa Clara, west of the Vizcaino desert; at Calmalli, in the middle of the peninsula, on the northern border of this same desert; and at San Francisquito, on the Gulf side, a few miles northwest of the old mission of Calamahue. These placer mines were long since abandoned. Other placer mines, notably at Miramar, near the gulf coast, and on the west base of the San Pedro Martir Mountains, have been working nearly or quite up to the present time. Efforts to develop mines in Lower California are at once met by three serious handicaps —first, lack of transportation facilities; second, the scarcity of water; and third, the equally important lack of fuel. As a consequence, the expense of maintaining operations in practically all parts of the peninsula are prohibitive except in the case of unusually productive mines.

The physiography and natural resources of Lower California, including game, whaling, fisheries, and other sea products, and the agricultural and natural plant products, are treated elsewhere under special headings.

Government.[1]

Lower California is a Federal territory officially divided for administrative purposes by the twenty-eighth degree of north latitude into a northern and a southern district, each administered by a governor appointed by the President of Mexico, the capital of the southern district being La Paz and that of the northern district Ensenada. In addition to being the head of the civil administration, the governor of each district is also commander of the military forces within his jurisdiction.

The northern district has for several years been administered by Gov. Esteban Cantu. For the first time in the history of the peninsula northern Lower California has an energetic and progressive governor, who is taking active steps to develop his territory. He is completing an automobile highway from Mexicali westward across the mountains to Ensenada. He has also built a military road, passable for automobiles, from Mexicali southward to San Felipe Bay, where he plans to develop a port, eventually, it is reported, to be connected with Mexicali by a railroad. The enormously rich agricultural lands of the delta of the Colorado lying tributary to Mexicali are of the same quality as, and in reality a direct extension of, the lands of the Imperial Valley lying immediately adjacent on the California side of the border.

In connection with the government of Lower California, it is of interest to know that during two short periods the peninsula has been in the complete possession of Americans. During the Mexican War in 1847 the forces of the United States occupied the principal points, with headquarters at La Paz, but relinquished them at the end of the war. In 1853 and 1854 the peninsula was again occupied and a government organized there by a band of American filibusters under Walker. This ill-advised adventure ended in disaster, and later Walker was killed on a similar filibustering expedition in Nicaragua.

Land Grants.

For many years much the larger part of Lower California has been covered by land grants of enormous size given ostensibly for colonization and developmental purposes. One company held nearly 12,000,000 acres. Under these grants, during the last half century, attempts were made to colonize various parts of the peninsula, mainly from the United States, all of which have been complete failures. Twenty families of Russian immigrants colonized Guadalupe Valley north of Ensenada in 1906, where they were reported to be doing well for several years, growing wheat, corn, oats, and other agricultural products. In July, 1919, the colony contained 45 families, most of whom were planning to move to the United States, owing to the difficulties of getting crops and to the uncertainties of a market. There is no question that the existence of the land grants, including the enormous area held by the Magdalena Bay Co., were exceedingly detrimental to the development of the peninsula as a whole.

[1] Statements regarding the government of Lower California were in type before the administrative changes of the summer of 192[illegible]

From 1915 to 1917 the Mexican Government canceled these grants, announcing in some cases that owners of land who had purchased from the holders of the grants previous to this cancellation might have their titles confirmed by proper representation to the Secretario de Fomento, in the City of Mexico.

The one part of Lower California which has become familiar to the people of the United States in recent years is Magdalena Bay, the surroundings and the coast of the peninsula for a long distance to the north of which were held under grant by the Magdalena Bay Co. (the Chartered Co. of Lower California), an American corporation. Rumors as to the occupation of Magdalena Bay by the Japanese and the sale of the great concession controlling the bay to foreign interests, owing to its proximity to our west coast, have repeatedly given rise in this country to excited newspaper publicity and editorial comment.

Some of the companies holding grants spent enormous sums of money in ill-advised efforts to colonize, making failures in some districts where efficient direction would certainly have produced considerable results.

The delta plain of alluvial lands of Lower California bordering the lower Colorado River and adjoining the southern border of the Imperial Valley of southeastern California is by far the richest and most important agricultural section of the peninsula. During recent years development in this area has been rapid and will continue. Long-staple cotton, melons, alfalfa, and barley have been the main crops, and it is reported that experimental plantings of rice and sugar cane have done well.

Population.

Owing to its desert character, Lower California has always been sparsely populated. With the exception of the large copper camp at Santa Rosalia, the population of the peninsula is mainly located in the northern and southern sections. In addition to the mining camp just mentioned, the main towns and villages are La Paz, San Jose del Cabo, Ensenada, Mexicali, San Ignacio, Mulege, Comondu, and La Purisima. The remainder of the inhabitants are in smaller mining camps, at insignificant villages, and on ranches.

The World War had considerable influence on the population of this region. This perhaps was shown most strongly at Santa Rosalia where it is reported that the mining activity was greatly increased and the population of this camp is reported to have numbered as high as from 7,000 to 8,000. Some of the smaller mining camps were closed through the effects of the war or previously, owing to revolutionary outbreaks. At the same time a number of the small mining camps were stimulated to increased activity.

According to the census of 1910 the population of the entire peninsula was about 32,600 inhabitants, of which the northern district held 9,760, and the southern district about 22,840. The population of the principal towns at this time was as follows:

Northern district.—Tijuana, 273; Mexicali, 462; Ensenada, 2,170; El Alamo, 307; San Quintin, 141; El Rosario, 359; Calmalli, 108.

Southern district.—Santa Rosalia, 3,807; Mulege, about 750; San Ignacio, 793; La Purisima, 609; Comondu, 1,050; Providencia, 1,653; Purgatorio, 2,057; La Soledad, 1,551; Magdalena Bay, 144; Todos Santos, 1,141; La Paz, 5,536; Triunfo, 2,341; San Jose del Cabo, 1,397.

During the last few years the population of the northern district of Lower California has fluctuated greatly, owing to rapidly changing conditions and especially to the great agricultural development which has taken place on the delta plain of the Colorado, tributary to Mexicali. According to the best information I can obtain from people personally familiar with the northern district the population in 1919 was approximately 16,000, distributed mainly as follows:

Municipality of Mexicali (September)	12,000
Tijuana	300
Tecate, and adjacent ranches	500
Ensenada	2,000
San Quintin	85
El Rosario	500
Calmalli	300

The municipality of Mexcali includes all of the agricultural section of northern Lower California. Its population is at a maximum during the cotton-picking season, in the fall, when it reaches a total of about 12,000. Of this number about 5,000 are Chinese and 300 to 400 are Japanese. The bulk of the remaining population is Mexican. Apparently owing to the development of labor difficulties, Governor Cantu, on September 10, 1919, issued an official decree prohibiting Asiatic immigration into the northern district of the peninsula.

About 600 Indians are reported to remain in northern Lower California, living in small scattered rancherias and isolated ranches.

Owing to its geographic location, Lower California is isolated from other parts of Mexico and has had much intercourse with California. My expedition through the peninsula was made after I had spent a considerable number of years in Mexico proper, and it was interesting to note certain characteristics of the people of the peninsula. We found them everywhere honest and friendly. There was a general absence of revolvers and machetes among the people of the peninsula, in marked contrast to the general custom of carrying one or the other of these weapons throughout most of the other parts of Mexico. During all of this trip, owing to the obviously peaceable and friendly character of the people, even in the remotest sections, for the first time in Mexican territory we felt no need of weapons for self-protection.

Wagon Roads.

Wagon roads in Lower California are few and poor in quality. The main road is that extending along the Pacific coast from Tijuana southward through Ensenada and San Quintin to beyond El Rosario. A nearly completed automobile road is being built from Mexicali westward across the mountains to join the road from Tijuana to Ensenada. Another road has recently been completed from Mexicali southward to San Felipe Bay. For many years a wagon road has been used from El Campo on the California border south along the top of the Pinal Mountains to El Rayo, and thence to San Rafael Valley on the west slope. A wagon road also connects Ensenada with San Felipe Bay on the gulf, passing through Trinidad Valley. San Fernando and the onyx mines on the Llano de los Buenos Aires are connected by road with the San Carlos and Santa Catarina Landings. A wagon road also connects the mining camp at Calmalli with Santo Domingo Landing on the Pacific coast. Another frequently used road connects La Paz with the mining camp of El Triunfo and Todos Santos on the west coast. Numerous other short roads have been built from time to time by mining and other companies at various points on the peninsula, but they are little used, many have been abandoned for many years, and none are kept in good condition.

Automobile travel is possible over most of the main roads in the northern part of the peninsula, but more or less frequent difficulties are encountered. A considerable part of the traffic throughout the peninsula is still maintained by the primitive means of pack animals over trails.

Seaports.

Port facilities in Lower California are scarce and usually of a primitive character. Customhouse officials and port facilities, such as they are, are provided at Ensenada, San Quintin, Magdalena Bay, La Paz, and Santa Rosalia. The last-named port is the shipping point for copper produced by the great El Boleo copper mine. There a breakwater has been built of slag from their furnaces, within which ships may be protected from the storms which sweep the gulf.

A number of bays along the coasts afford a certain amount of shelter, but there is no population back of them to encourage their use. Most landings in the peninsula are made from open roadsteads such as exist at San Carlos, Santa Catarina Landing, Playa Maria, Santa Rosalia Bay, Santo Domingo Landing, Cedros Island, San Jose del Cabo, and at numerous points along the gulf coast.

Healthfulness.

As a whole Lower California is characterized by the remarkable healthfulness of its climatic conditions. This is especially the case in the northern half of the peninsula. In the southern half, malaria occurs in certain places and there have been outbreaks of yellow fever from time to time, the infection being brought from Mazatlan and other points on the Mexican mainland.

In 1883 a severe epidemic of yellow fever visited the southern end of the peninsula, extending as far north as Magdalena Bay and San Ignacio.

Map.

The accompanying general map of Lower California (see Pl. 35) is the most complete yet published. The coast line and islands are accurate, being from Hydrographic Office charts based on surveys of the United States Navy. The location of the mountain summits and their altitudes throughout the peninsula are practically all from the same source. The maps of Dr. Gustav Eisen covering the southern part of the peninsula, published by the California Academy of Sciences and the American Geographical Society, have been the basis for that region. Manuscript maps from David Goldbaum have supplied the main features of the northern district, supplemented by others covering certain districts by John B. Burnham, Ottomar H. Van Norden, and E. W. Funcke. To the foregoing have been added data obtained during the expedition by E. A. Goldman and the author. It is fully recognized that this map contains numerous inaccuracies of detail, but it is hoped that it will serve a useful purpose until more careful surveys are made.

Through the lack of designations for numerous geographic features, I have thought it advisable to propose names for some of them. The names are mainly those of some of the early Spanish explorers and missionaries, who first made known the coast and interior of the peninsula, and of certain American naturalists, whose scientific work has given us much of our information concerning the wild life of this region. These names are as follows:

Cerro Kino (4,289 feet), in honor of Padre Kino, one of the early missionary explorers.

Cerro Salvatierra (7,062 feet), in honor of Padre Juan Maria Salvatierra, one of the early missionary explorers.

Cerro Junipero Serra (3,189 feet), in honor of Padre Junipero Serra, one of the early missionary explorers.

Cerro Ugarte (5,400 feet), in honor of Padre Juan Ugarte, one of the early missionary explorers.

Anthony Peak (4,593 feet), in honor of the naturalist Alfred W. Anthony, to whose work through a series of years we are indebted for much information concerning the birds and mammals of the peninsula.

Bryant Peak (4,485 feet), in honor of the naturalist Walter L. Bryant, whose explorations and publications added much to our knowledge of the bird and mammal life of the peninsula.

Goldman Peak (5,000 feet), in honor of the naturalist Maj. Edward A. Goldman, who made the expedition with me in 1905 and 1906.

Brewster Peak (4,485 feet), in honor of the naturalist the late William Brewster, who published a notable account of the birds of the southern district.

Llano de San Quintin, the plain bordering San Quintin Bay.

Vizcaino Desert, in honor of the navigator Sebastian Vizcaino.

Llano de San Bruno, the plain on the Gulf coast where the village of San Bruno is located.

Magdalena Plain, the coastal plain fronting Magdalena Bay and Island.

ACKNOWLEDGMENTS.

It gives me pleasure to express my grateful appreciation of assistance received in connection with this report. Those who contributed to the map are named above. Much of the success of the Biological Survey expedition was due to the faithful and efficient services of Maj. E. A. Goldman, whose photographs illustrate the report. Mr. A. W. Anthony contributed valuable notes made during his long experience in the peninsula. Mr. Joseph K. Hutchinson, Capt. H. W. Cochran of the United States Army, Dr. J. W. Mixter, Mr. Dale Bumstead, Mr. Lincoln Ellsworth, Mr. David Goldbaum, and Mr. O. A. Pratt, of the Federal Horticultural Board, have supplied notes and information which have been invaluable. It is a pleasure, also, to mention the generous hospitality of Mr. W. J. Heney, resident manager of the Chartered Co. of Lower California, which at the time of our visit controlled the Magdalena Bay concession. We were entertained

Fig. 1.—Cocopah Indian and brush hut on Hardy River in delta of Colorado River.

Fig. 2.—San Matias Pass, altitude 1,581 feet, between Santa Inez and San Pedro Mártir Mountains. View looking southeast, north side of pass characterized by rocky hillocks of Cretaceous granite and small cacti.

Fig. 1.—Valley of Santo Tomas, south of Ensenada. (Photograph from David Goldbaum.)

Fig. 2.—Valley of El Rosario, south of San Quintin. These are typical agricultural villages in northern Lower California. (Photograph from David Goldbaum.)

by him during our work in the Magdalena Bay section and were given facilities which enabled us to accomplish much that would have been impossible without his friendly assistance.

THE BIOLOGICAL SURVEY EXPEDITION.

During many years the Biological Survey had been making detailed studies of the distribution of bird and mammal life and their environmental relations in the arid regions of the southwestern United States. It finally became of considerable importance to have first-hand information on the little-known adjacent and closely related peninsula of Lower California. Early in 1905 it was decided that a Biological Survey reconnoissance of the peninsula should be undertaken. I was placed in charge of the proposed expedition, with Mr. E. A. Goldman as my assistant. The expedition began in March, 1905, and ended the 1st of February, 1906. During this period we traversed the entire length of the peninsula and crossed it eight times from coast to coast. With the exception of a few subsidiary boat trips in the delta of the Colorado and to the coastal islands, the work was all done with horses and pack animals and included more than 2,000 miles of travel in the saddle.

In order that the delta of the Colorado might be covered before the main work was begun, Mr. Goldman joined Dr. D. T. MacDougal, botanist of the Carnegie Institution of Washington, on a boat expedition to the delta region. They left Yuma, Ariz., March 21; descended the river and made a brief stay at Colonia Lerdo, on the Sonora side; crossed the Colorado and camped at the mouth of the Hardy River, in Lower California. The spring of 1905 was marked by unusually high water in the Colorado, and much of the delta country was overflowed, especially the Hardy River district. (See Pl. 23, Fig. 2.) The party worked its way up the flood plain of the Hardy, and from April 5 to 15 camped at the east base of the Cocopah Mountains, exploring for plant and animal life the adjoining desert plain and the Cocopahs to their summit. They then ascended the Hardy to Volcano Lake and camped on New River. Many curious small mud cones built up by escaping gases and called mud volcanoes are located near Volcano Lake. (See Pl. 21, Fig. 2.) On April 21 the party left the boat and proceeded by wagon to Calexico, just within the border of California, where this section of the work ended.

The middle of May I met Mr. Goldman at San Diego, and on May 14 we proceeded by gasoline launch to study the bird life on the Coronados Islands, a group of rocky islets lying about 7 miles off the extreme northwestern coast of Lower California. We camped one night on the larger island, and after visiting the other islets and securing some interesting specimens of birds and notes on the species breeding there returned to San Diego, May 15. On the way back we were much interested, when a few miles off the mouth of San Diego Harbor, to see a number of Sabine gulls scattered about feeding on the tide lines formed by the currents in the smooth sea. This was, I believe, the first record of these beautiful birds at San Diego.

On the evening of May 16 we left San Diego by steamer and arrived the following morning at Ensenada, the most northerly port and the capital of the northern district of the peninsula, about 65 miles from San Diego. Ensenada, which contained only about 1,000 people at this time, is situated in a small valley at the head of Todos Santos Bay and was formerly much more prosperous than at the time of our visit. To the northeast the town is backed by abruptly rising, high, grass-grown hills, the steep slopes of the coast range rising farther to the east at the head of the small valley extending from the shore of the bay a short distance inland.

At the time of our visit Col. Celso Vega was governor of the northern district. He received me courteously and assisted in furthering the objects of our expedition. Ensenada was also the headquarters for the Lower California Development Co., an English corporation possessing an enormous land grant in the northern part of the peninsula, which they had purchased from the former holders. Some years before our visit this company had colonized the land about Ensenada and at San Quintin on the coast farther south for farming and fruit growing. Many people were attracted there from the United States and elsewhere, but the colony proved a failure, and nearly all of its members had left, many having lost all they possessed.

We remained some time at Ensenada studying the native bird and animal life in the country surrounding the town, and outfitted for our long overland trip down the peninsula. From May 20 to 22 we visited the Todos Santos Islands, at the mouth of the harbor. This trip was especially notable through the discovery that an extensive migration of Pacific loons was taking place several miles offshore. These birds were flying northward in a broad belt passing about a mile inside of the islands. The weather was pleasant and they were winging their way in a continuous procession, singly, or sometimes two or three in a group, often spaced by intervals of several hundred yards, but during the hours in which I observed them there was no definite break in the flow of birds. The total number which passed during the two days in which they were observed must have been very great. The flight of these birds northward along this coast in such numbers was especially interesting in view of the fact that theretofore they had rarely been recorded from anywhere in the peninsula.

On account of the sparsely populated and desert character of Lower California, the poorly marked trails, and the few and widely scattered watering places, it was important for us to secure a good outfit for our expedition. Unfortunately, at the time of our visit Ensenada was almost depopulated, the most energetic part of the inhabitants having gone with their teams to the Imperial Valley, Calif., attracted by the abundance of work and high wages on irrigation enterprises. Thus it was impossible to obtain satisfactory men or good horses and mules. After much delay we succeeded in employing two camp men who claimed to know all trails throughout the northern half of the peninsula. Four very ordinary saddle horses and four small pack mules were secured. We were assured by several residents of Ensenada that it was useless to try to journey down the peninsula with saddle horses, for they would soon die, since only good mules could stand the necessary hardships of such a trip. Our experience disproved this, for three out of the four small saddle horses made the entire trip. The poorest horse became exhausted and was traded for another about midway on the journey.

It is true, however, that we found conditions exceedingly hard for our stock, and it was only by exercising the most judicious care in stopping at frequent intervals where the scanty forage appeared most favorable, in order that the animals might rest and recuperate, that the trip was practicable. All of our animals were forced to depend on such forage as they could find, since the sparsely inhabited character of the country rendered it impossible to supply them with grain or other cultivated feed of any kind, except to a small extent at long intervals.

The men we hired as guides proved less worthy than the animals, for after a few days' travel they were forced to admit they did not know the trails or water holes. No other men were available, so we were compelled during a large part of the journey across hundreds of miles of desert to depend for guidance on our own skill in following dim trails, and on the information concerning the few water holes which was obtained from the occasional people encountered. Fortune favored us, however—we found water at all of the watering places we visited throughout the journey, and thus escaped any serious discomfort from thirst.

South of Ensenada three trails were early established by the Spanish missionaries and are still in use. One follows near the Gulf coast and is known as El Camino del Golfo; another, down the west coast, is El Camino del Pacifico; and the third, down the mountainous backbone of the interior, is called El Camino de en Medio. The last, although rougher than the others, has more frequent waterholes and better grazing, and was the one mainly followed by us, though we crossed back and forth to the others.

On May 24 and 25 Goldman made a successful side trip from Ensenada 28 miles down the coast to Santo Tomas to obtain topotypes of a pocket gopher (*Thomomys aphrastus*)[1] described a few years before from the locality.

On May 31 we left Ensenada with our pack train on the journey which ended about nine months later at the southern end of the peninsula. A well-worn wagon road led us easterly through a little valley, up a gentle slope, and thence into a canyon cutting the western face of the low, abruptly rising range which borders the coast in this section of the peninsula. Our

[1] Elliott, Field Columb. Mus., Zool. Ser., III, 219, June 1903 [= *Thomomys bottae nigricans* Rhoads].

first camp was at about 1,800 feet altitude, near the upper end of the canyon, among picturesque live oak trees with short massive trunks, and huge wide-spreading branches, some of which were nearly as large as the main trunk.

June 1 we ascended the canyon about 2 miles, and, crossing a divide at about 2,800 feet altitude, came out into San Rafael Valley. This is a pretty, elevated valley, 18 or 20 miles long in a northwesterly and southeasterly course, and from 3 to 10 miles wide. It forms the upper part of the drainage of the Arroyo de San Rafael, which at the lower end of the valley passes the old Spanish settlement Real del Castillo, and on its way to the coast north of Ensenada passes the old Guadalupe Mission. The valley forms an open plain bordered on the west by the coast range and on the east by the higher Sierra Juarez, or Laguna Hanson Mountains. Our road led a few miles up the valley, by the Ojos Negros cattle ranch, and then easterly about 9 miles to the little Indian village of La Huerta, where we camped at an altitude of 2,800 feet, immediately below the Indian houses. Here a small stream flows through the broad lower end of a canyon in the foothills of the Sierra Juarez. A dozen or more Indian families occupy a few huts scattered among small fields and orchards, where they grow peaches, apricots, corn, beans, and other garden vegetables.

The western slope of the coast mountains facing Ensenada has Upper Sonoran vegetation similar to that of the same slope near San Diego, but in the southern end of San Rafael Valley there is a mixture of mesquites, yuccas, and other Lower Sonoran species. The bottom of the valley is covered with grass and small scattered shrubs, the latter increasing in size and abundance in the bordering foothills on both sides. All the way from Ensenada to La Huerta the rocks are mainly of granite, and the east side of San Rafael Valley is covered with loose granitic gravel. We saw many signs of sheep along the way and learned that large numbers were being grazed in the rough country on the west side of the peninsula from the northern border south to San Quintin. Most of the shepherds employed were Basques from the south of France.

June 3 we left the wagon road at La Huerta and followed a winding trail for about 6 miles easterly to La Republica, an abandoned gold mine and stamp mill; then for about 12 miles northerly to a small meadow in an open ravine near the top of the range at 4,800 feet, where we camped. The entire west slope of the Sierra Juarez range in this section is broken only by long, rounded, undulating ridges, rising so gently that for long distances we appeared to be traversing a slightly broken plain, covered with low brush and scattered rocks. Our camp was in a small group of stunted live oaks about a mile below the El Rayo ranch on top of the mountain. The slopes all about camp were covered with granitic sand and gravel, with large rounded granite rocks projecting here and there. Over these slopes a thin growth of small shrubs and widely scattered scrubby pines gave the landscape a poverty-stricken appearance. The morning of June 4 a sharp frost coated with white the vegetation in the bottom of the meadow by our camp.

June 5 we moved about 8 miles northeasterly, passing El Rayo ranch, and made camp at an altitude of 5,400 feet on top of the mountain near Laguna Hanson. El Rayo ranch was formerly the Hanson ranch occupied by an American of this name with his cattle. He was murdered near here, and the place is now one of the ranches of an American company with headquarters at Ojos Negros, in San Rafael Valley. The Laguna Hanson still bears the name of the original owner, and his name is often, but erroneously, applied to the mountains on which his ranch was located. It may be of passing interest to note that the only disagreeable and unfriendly attitude toward our work met during our entire expedition was at this American ranch.

At El Rayo ranch the trail entered a good wagon road which follows the top of the range from Campo, just within the California border. The summit of the Sierra Juarez is a rolling mesa, sloping to the west with low, usually bare, granite ridges and gigantic piles of huge rounded rocks. These rocks were often too huge and smoothly rounded to be climbed by a man. They were evidently the results of rapid decomposition of the granite. Laguna Hanson is a shallow pond about half a mile across, situated in a small mountain park and surrounded by low growth of Jeffrey pine. Two smaller ponds are located near the larger one.

June 9 we left Laguna Hanson and followed the wagon road southerly about 14 miles along the top of the mountains, repassing El Rayo ranch and reaching an abandoned sawmill on a small stream in a pretty little valley. Here we lost several hours trying to find the trail, which continues southward along the mountain, but the many old log roads confused us, so we abandoned the idea of keeping this course and turned down the west slope, following the wagon road 8 miles, and camped at an altitude of about 4,200 feet by a little stream in the lower end of a small canyon. This was just above the village of Sangre de Cristo, at the southeastern border of the San Rafael Valley.

June 10 we traveled southeasterly about 22 miles, crossing the southern end of San Rafael Valley and camping at 3,700 feet altitude by a small spring and marshy meadow near the base of a hill called Cerro Colorado. This was one of the regular camping places for teamsters on the main wagon road for freighting supplies from Ensenada to the American mining camp at Alamo, and as a result grazing for stock was scarce in its vicinity. Cerro Colorado lies at the head of the drainage flowing into San Rafael Valley and is in the midst of the brush-grown hill country which limits the southern end of this valley.

June 11 we continued about 15 miles southeasterly along the wagon road through rolling hill country and, crossing a divide at about 4,500 feet, descended to Alamo, on the west end of an open plain, at an altitude of about 3,400 feet, close to the base of some low, abrupt, and barren rocky ridges. From Alamo the plain, which has a width of from 6 to 15 miles, extends easterly about 20 miles to the west base of the southern end of the Sierra Juarez. It is bordered on the northern side by series of low hills and on the southern side by low rounded ridges and mesas, which merge into the hills bordering Trinidad Valley. Most of plain and adjoining hills are covered with a fairly abundant growth of junipers with some pinyon pines, but most of the larger growth for a dozen miles around has been cut for the needs of the mines at Alamo and the available supply appeared to be approaching exhaustion.

Alamo, with its vacant houses and dilapidated appearance, was a typical broken mining camp. There were many signs of former activity here on a considerable scale, but at this time only a few men were working. New supplies were being sent in and a revival of work was being announced with the usual sanguine expectations.

At Alamo we replenished our supplies and then traveled about 6 miles easterly, along one of the several wood roads which radiate from the camp, to La Posa, a muddy water hole on the plain, where we camped. The water hole was much frequented by cattle, and the stagnant water was very bad. The morning of June 12 we continued easterly about 10 miles, crossing numerous low, rounded ridges of granite bowlders, to a small deserted house by a spring known as Rancho Viejo or Los Batequis, where we camped for a few days. This place is located at an altitude of 3,500 feet on a small knoll among the pinyons and junipers.

Directly across the open plain from Rancho Viejo, close to the base of the Sierra Juarez, we saw smoke rising daily from the fires of Indians living at the old Santa Catarina Mission, but they did not come near us. A band of wild horses was ranging about Rancho Viejo and gave us much trouble by coming in at night and leading off our stock. A single night among the wild horses gave our broken stock such a feral state of mind that only their hobbles prevented their leaving us forever, and when finally rounded up in the morning they would gaze at us wild eyed, and snort and tremble when first touched. Once bridled and saddled their lack-luster eyes and plodding gait showed the force of habit over instinct.

June 16 we traveled southeast from Rancho Viejo along a good wagon road over the rolling and gradually rising plain covered with pinyons and junipers, for about 16 miles to the top of the northern rim of Trinidad Valley, at an altitude of about 3,800 feet. From the rim a dug road descended the slope abruptly to the bottom of the valley, about 1,000 feet below. There the road forked and we turned to the right about 4 miles down the valley and camped at Campbell's cattle ranch at 2,600 feet altitude. This ranch is near the lower end of the valley and was our headquarters while we were working this locality. Trinidad Valley is a basin about 18 miles long east and west and about 3 miles broad in the middle, narrowing gradually toward each end. It is open grassland in the lower part, with bushes on the sides and much cactus,

View looking north across San Felipe Bay. Good water is found a few feet below the surface on a flat bank of stone. (Photograph from David Goldbaum.)

FIG. 1.—Stream at mouth of La Providencia Canyon, east base of San Pedro Martir Mountains. Note huge granite bowlders brought out of canyon by flood waters and in places appearing like a glacial moraine. (Photograph by Dale Bumstead.)

FIG. 2.—Copal tree (*Elaphrium macdougalii*) near San Felipe Bay. The northern representative of a group of Arid Tropical trees common in western Mexico.

yucca, agave, and other desert growth for miles of its upper end and in the pass. A small stream flows down a few miles of its lower end and drains through a rocky canyon leading to the west coast.

On June 17 we left our extra supplies at Campbell's and started for San Felipe Bay, on the Gulf of California. We traveled 16 miles easterly up the valley to San Matias Pass, following a continuation of the wagon road by which we entered the valley. The pass is an open gap about one-fourth of a mile wide with a nearly flat bottom and gradual descent each way. (See Pl. 2, Fig. 2.) It separates the southern end of the Sierra Juarez from the northern end of the San Pedro Martir Mountains. Just before entering the narrowest part of the pass we turned to the right and followed a dry wash up a little side valley and then through a rocky canyon in the west side of the northern point of the San Pedro Martir Mountains for about 3 miles in all to San Matias Spring, near the head of the canyon. The spring, the only water near the pass, gives a small trickling stream which runs down the canyon only a short distance before it sinks into the sand.

June 18 we crossed a low ridge of the mountain just above and to the east of the spring and entered the head of Windy Canyon, which winds down the east slope about 8 miles to the sloping desert plain on the east base of the San Pedro Martir Mountains. The entire bottom of Windy Canyon, which has high rocky walls, is so filled with a wash of granitic sand and gravel from the disintegrating sides that it presents a smooth, easily traveled, gently descending slope. The canyon is dry and very barren throughout its course, but on the desert at its mouth we found the basal plain covered with a vigorous growth of cactus, yucca, mesquite, ironwood, covillea, paloverde, fouquieria, and other desert plants. The trail turns abruptly to the right a short distance out on the plain and skirts the base of the mountain for about 12 miles to the mouth of Esperanza Canyon, crossing slopes made up wholly of loose disintegrated granite.

The east front of the San Pedro Martir Mountains rises abruptly in a tremendous escarpment of bare cliffs and rocky slopes, 4,000 to 8,000 feet above the basal plain, with several canyons cutting huge, ragged gashes into its face. In cool weather small streams flow down the bottom of the larger canyons, sometimes running a mile or so out on the plain before sinking into the sand, but in dry hot weather commonly retreating a mile or more up the canyons. Extending out on the plain from the mouth of Esperanza Canyon is a great alluvial fan, or delta, built up of disintegrated granite with a ridge of bowlders along its middle. These bowlders vary from 1 to more than 6 feet in diameter and extend a mile down the slope, showing the enormous force of the occasional floods which pour down the canyon. At the time of our visit a small stream of clear, pure water flowed down the wash and disappeared in the sand just outside the mouth of the canyon. In the morning this stream flowed several hundred yards farther than in the evening, retreating during the day, owing to evaporation caused by the sun. Swarms of mourning and white-winged doves and some other birds, as well as a small band of half wild horses ranging on the adjacent desert, were watering here, but we saw no tracks of antelope or other game animals.

June 19 we continued southerly along the sloping basal plain about 12 miles to an altitude of 2,000 feet at the mouth of La Providencia Canyon, which also had a small clear stream of pure cold water, clear as crystal, flowing to its mouth. (See Pl. 5, Fig. 1.) La Providencia is another high-walled canyon scoring the east face of the range. It is located just south of Cerro de la Encantada, the highest peak in the range, at the most outstanding point on the desert front of the mountains. Halfway between Esperanza and La Providencia Canyons we passed the mouth of Canyon Diablo, the wildest and most rugged canyon in this front of the range. It heads on the west side of Cerro de la Providencia, and descends first northerly and then easterly, thus cutting around the west and north sides of the mountain. From the mouth of La Providencia Canyon there extends for more than a mile down the middle of its great alluvial delta another gigantic stream of flood-piled bowlders, which vary in diameter up to 6 or 8 feet. This great bed of bowlders renders access to the water in the mouth of the canyon difficult except by following closely the intricate course taken by the few half wild

horses and cattle which come here to drink. This bowlder stream has an interesting resemblance to a low glacial moraine.

San Felipe Bay, our destination on the Gulf of California, lies about 30 miles easterly from La Providencia Canyon. San Felipe Valley, about 10 miles across, lies along the eastern base of the San Pedro Martir Range, bordered on its eastern side by the Sierra San Felipe, a low barren range parallel to the gulf coast, and reaching an altitude of about 4,000 feet. Between the southern end of this range and the Sierra Santa Rosa, nearly opposite but a little southerly from La Providencia Canyon, is Buena Vista Pass, through which the wagon road extends to San Felipe Bay on the gulf. The weather had become exceedingly hot, and in order to traverse the desert between La Providencia and San Felipe Bay with as little discomfort to our stock as possible, we left camp at 3.30 a. m., June 20, and made our way slowly through the darkness down the slope easterly to the bottom of the valley, which has an altitude of 1,400 feet, 600 feet below the mouth of the canyon. The bottom of the valley where we crossed is covered with a broad belt of sand dunes capped with mesquite thickets, and with the intervening open spaces so thickly filled with burrows of large kangaroo rats (*Dipodomys deserti*) that it was difficult for our animals to struggle through. As the sun came up over the range in front we were much relieved to reach firm ground again. Near the base of the low mountains on the east side of the valley we found traces of an old wagon road laid out many years ago from Ensenada by way of Trinidad Valley and San Matias Pass to San Felipe Bay, when it was planned to colonize the shores of the bay and to land there the supplies for Ensenada and other parts of northern Lower California, which were to be transported overland by wagon. Our course lay directly across the valley until we reached the old road along the west base of the Sierra de San Felipe and then turned southerly among low scattered foothills. After passing through these we turned again easterly at an altitude of 1,600 feet and went down the dry sandy bottom of the broad arroyo leading from the valley through Buena Vista Pass, which forms a deep gap between the mountains and leads directly toward the gulf.

We soon reached the east side of the mountains at a point called Buena Vista, whence the broad expanse of the gulf could be seen. Buena Vista has an altitude of 600 feet on the western border of the gently sloping desert plain which extends thence to the gulf, a distance of about 15 miles. The surface is here broken by scattered, barren hills and low mountains. The day was extremely hot and our animals were much exhausted when, late in the afternoon, we rode through a gap among some hills and came in sight of the narrow line of green mesquites in the flat behind the sand dunes on the beach at San Felipe Bay. We saw no sign that a house had ever been built here, but a strong signal post stood on the beach just in front of two water holes, 3 or 4 feet deep, dug in the clay flat near the mesquites. No recent trace of human visitors was visible, but evidently numbers of coyotes and turkey buzzards visited the water holes regularly, and the fluid was so foul in consequence that even our excessively thirsty animals refused to drink it. After some hard work the holes were emptied and the vile-smelling mud on the bottoms and sides cleaned out. The new water which quickly seeped in was usable, although offensive in odor and taste. We made camp a short distance from the water under a fine, wide-spreading mesquite tree. Directly offshore, in front of the bay, Consag Rock stands out like a great sail, its high cliffs whitened by the droppings of sea fowl. San Felipe Bay, several miles in width, is not deeply indented, and on the west and south sides is low and bordered by a narrow belt of sand dunes. The north side is limited by a low, isolated, rugged mountain of uniform black color, known as San Felipe Point, which projects as a bold headland into the gulf. (See Pl. 4.) On the bay side of this mountain is a little rounded tidal lagoon, which fills through a narrow channel at high tide. A low wall of stone had been built nearly across the entrance, and we learned that this lagoon has served as a natural fish trap since prehistoric times. When, at unusually high tides, the lagoon is full of water and contains many fish the openings in the wall are closed across the entrance channel, and as the tide falls the water runs out between the stones leaving the fish stranded. During our visit the tides were low, although rising and falling 15 or 20 feet, and most of the time the moist bottom of

the lagoon swarmed with fiddler crabs (*Uca crenulata*). The black rocks of the headland within a few feet of the water line were covered with black isopods (*Ligida exotica*), which appeared to thrive in the full glare of the sun on the rocks when they were uncomfortably hot to touch. The water of the gulf along shore at this time was surprisingly warm, and many small sharks and sting-rays frequented the shallows along the beach. After 8 o'clock the heat was intense, but about 11 o'clock a sea breeze began to blow from the gulf and the rest of the day was more comfortable.

From San Felipe a rarely used trail leads southerly along the coast, passing several mining prospects, to Miramar, a mining camp which was in operation in 1905 near El Tule Arroyo, on the gulf slope, almost east of the Onyx mine. Water is very scanty and occurs only at wide intervals along this trail, and prospectors are reported to have died of thirst while traversing it. Another trail leads northerly up the coast and passes through a large arroyo separating the Sierra de San Felipe and Sierra Pinta to Poso Salado and Tres Posos, to the west side of Laguna Maquata and on to Mexicali.

The plains from the base of the San Pedro Martir Mountains to San Felipe Bay have a characteristic desert flora, including such species as *Pachycereus pringlei*, several genera and species of other cactuses, *Fouquieria splendens*, *Prosopis glandulosa*, and *Covillea glutinosa*. In addition, about 3 miles inland, near the north base of the high Sierra Santa Rosa, which rises abruptly west of the bay, there was a narrow belt of small broad-topped trees which in foliage, color of bark, and general superficial appearance curiously resemble an irregular growth of short-trunked apple trees. They are *Elaphrium macdougalii*, one of the most northerly representatives of the copals, a group of wide distribution farther south in Lower California and on the tropical mainland of Mexico.

Day by day the heat grew more intense at San Felipe and, in order to make the return trip to the mountains as easy as possible for our stock, we left the bay at 2 p. m., June 25, and traveled back along our old trail about 15 miles to Buena Vista, where we made a dry camp on the clean white sand of the wash which we had followed on our way to the gulf. Then by moonlight, at 1 a. m., June 26, we retraced our way up the wash through the mountains and across the valley to La Providencia Canyon. During the early morning hours the air was so cool, as was often the case on the desert in summer, that we were glad to wear our sweaters, but as we entered the mouth of the canyon, the sun came up over the San Felipe Mountains and its blazing heat at once foretold another excessively hot day, with the temperature far above 100° F. in the shade. Owing to the exhausted condition of our stock from the scanty feed and the exertion of crossing the hot desert, we remained in this canyon for a day while the animals recuperated.

June 27 we started back to Trinidad Valley, camping again at Esperanza Canyon and San Matias Spring, and reaching Campbell's ranch June 29. During the 10 hot days between our first sight of Esperanza and La Providencia Canyons and our return from the gulf, the small streams which had reached their mouths had notably decreased and now sank into the sand much farther up the canyons. In midsummer the lower end of the water must be a mile or more above the mouths. For some days after our return to Trinidad Valley we were occupied in studying the birds and mammals living there. Several dens of the desert fox (*Vulpes macrotis*) were found in the bottom of the valley and some specimens secured. On July 3, I left Goldman to complete the work in the valley, and with Campbell made a rapid trip in a light wagon over a fairly good road to Ensenada to ship our specimens and renew supplies.

We reached Ensenada July 5 and found the schooner *Academy*, from San Franciso, in port on its way to the Galapagos Islands with a scientific expedition from the California Academy of Sciences. The expedition was in command of Mr. R. H. Beck, and the party included several enthusiastic young naturalists who made fine collections in many branches of zoology, and in plants wherever they landed.

July 8 I was back in Trinidad Valley and found that, according to our plans, Goldman had started with the outfit July 4 for the northwestern base of the San Pedro Martir Mountains, where he was to remain until I overtook him.

July 9 I left Campbell's ranch alone on horseback and followed Goldman's trail to the southeast across Trinidad Valley, and then through rolling and rocky hills overgrown with scattered pinons and junipers. About 8 miles from Campbell's I passed an Indian rancheria called Arroyo de Leon, where a small group of huts was located. Goldman had stopped here for his midday rest and found a Mexican camped close by who pretended to be a trader, but was in reality robbing the Indians. This man was reported to make frequent trips among the few Indians of this district ostensibly to purchase beeswax for cash, or for a few trade goods he carried, but his real purpose was to gamble with the inexperienced Indians until he had won their money and as many horses as possible. When Goldman passed he had already won four horses. This shows that the pitiful remnants of the tribes which once populated the peninsula are still being preyed upon by their so-called civilized superiors. The head man among the Indians here and in other Indian villages in Lower California is called El Capitan, a name formerly in common use among the Mission Indians of southern California.

Continuing through the same rolling hills about 7 miles southeasterly from Arroyo de Leon and 15 miles from Campbell's, at an altitude of 3,600 feet, I came to a spring and two deserted houses known as Poso Luciano, where I camped for the night. July 10 I followed Goldman's trail southeasterly across low brushy hills for about 12 miles to the mouth of a canyon in the basal foothills of the San Pedro Martir Mountains, at an altitude of 5,300 feet. Here he was camped by a small stream which flows through the flat at the mouth of the canyon and sinks into the sand just below. This place is known as El Piñon, and the flat and adjacent hillsides are covered with pinyon trees, making it a favorite resort for Indians during the harvest of pinyon nuts. An Indian village was once located here, but water became scarce and it was abandoned years ago.

July 11 we left El Piñon and traversed a series of low hills and ridges covered with a vigorous growth of large bushes and scattered pinyon trees flanking the basal slopes of the main range. Our course was southerly, mainly with no sign of a trail, and travel was slow on account of the dense growth of rigid bushes, among which it was difficult to force a passage. We finally reached the bank of a small swift stream of clear water flowing along the base of the main slope of the mountains at an altitude of 4,800 feet, where we camped. The stream, probably the headwaters of the Arroyo de San Rafael, was densely bordered by a vigorous growth of willows, and was the largest we had seen on the peninsula. Here our animals fed eagerly on the juicy grasses along the water's edge, and we found the fresh green of the willow thicket and the sound of water rushing over its rocky bed extremely refreshing after our weeks on the sun-scorched deserts.

The morning of July 12 we climbed without any trail the steep open slope of the San Pedro Martir Mountains directly above camp, and when well up near the top of the main ridge came unexpectedly into a well-made trail along the bank of a large ditch, which wound around the mountain side to the Socorro placer mines a few miles to the south. A trail soon left the ditch and led up an extremely steep rocky slope to the top of the mountain. Thence we crossed several rounded ridges covered with an open growth of yellow pines, and about 10 miles from our camp, at about 7,200 feet altitude, found two log cabins and a corral built on the banks of a small stream in a flat near the upper end of a small canyon. Here patches of aspens were growing among the pines on north slopes, and grass and other herbage on the open flats. This was Vallecitos ranch, a summer cattle ranch unoccupied at the time of our visit. We arrived in the midst of the first storm of the summer or rainy season, a hard thundershower of rain and hail, which continued for more than an hour.

The same afternoon I rode over the surrounding country and about a mile and a half southeast of the ranch found the Vallecitos or "Little Valleys," the locality where we wished to locate for our first work on the mountain. The Vallecitos are a series of beautiful flat-bottomed grassy parks at an altitude of about 8,000 feet, with gently sloping borders overgrown by an open forest of yellow pines (*Pinus jeffreyi*) mixed with a few other conifers. (See Pl. 6.)

July 12 we moved camp to the lower end of the Vallecitos, where in the arroyo a little water comes to the surface. Two brothers named Gay and a friend from Riverside, Calif., had been

Fig. 1.—North slope near Vallecitos, about 8,000 feet, San Pedro Martir Mountains. The view shows a pure [illegible], Jeffrey pine (*Pinus jeffreyi*), and lodgepole pine (*Pinus contorta*).

Fig. 2.—[illegible]

FIG. 1.—Meadow at La Grulla, San Pedro Martir Mountains (about 7,000 feet). Note the thin fringe of Jeffrey pines around the border with bare granite ridges rising beyond.

FIG. 2.—Meadow at La Grulla with Jeffrey pines and huge granite bowlders about the border.

camped here for some time, hunting deer and enjoying the beautiful surroundings. They reported deer rather common, but were shooting only what they could utilize. They hunted specimens for us a few days and then left on their way to the border. On the easterly side of Vallecitos a long, high, narrow ridge forms the main crest of the mountain and reaches an altitude of about 9,000 feet. On the southwesterly slope of this ridge several little springs and streamlets were found in the heads of small canyons leading down toward Vallecitos, but none flowed down the sandy wash leading through the park. This high ridge forms the westerly wall of Canyon Diablo, and from the crest above Vallecitos we had an impressive view down the rock-walled gorge. Canyon Diablo heads southwesterly from the Cerro de la Providencia, the culminating peak of the range, and swings around the western and northern sides of the peak to the open desert between Esperanza and La Providencia Canyons. In front of us to the east, directly across the upper canyon, La Providencia Peak rose to an altitude of over 10,000 feet, forming the sharp crest of a narrow cockscomb ridge of bare granite which, cut from the main mass on two sides by Canyon Diablo, extends northerly as a part of the eastern wall of the range, its spur-like character apparent only from the top of the range where we stood. The view was uninterrupted out through the mouth of the canyon to the desert valleys 8,000 feet below and beyond over the summits of the scattered desert ranges to the lower Colorado River and across the northern end of the Gulf of California to the high mountain ranges far in the interior of Sonora. The view over the low desert ranges was like looking down on a gigantic relief map. Great alluvial fans or deltas extending out from the mouths of canyons were conspicuous everywhere, and several fine examples of mountain ranges 2,000 to 3,500 feet high almost completely buried in their own disintegrated material were seen.

A few stunted pinyon trees were growing in crevices in the southern faces of Canyon Diablo walls up to 9,000 feet altitude. Many mountain quail with coveys of young of various ages were seen above Vallecitos on the west slope of this high ridge, and mule deer were numerous in this locality.

On July 18 we broke camp at Vallecitos and crossing the plateau southwesterly descended a steep and rocky trail about 12 miles to La Grulla (The Crane) meadows. There are three of these meadows situated on a plateau more broken than that at Vallecitos and about 1,000 feet lower, thus having an altitude of about 7,000 feet. La Grulla is on the southwestern slope of the mountain and, like Vallecitos, is the type locality of several species of birds and mammals. The main meadow at La Grulla is a narrow, winding, grassy valley several miles long, amid a beautiful open pine forest, with two small ponds in the bottom and gigantic granite bowlders scattered in profusion, singly or in groups, along its sides, especially near the lower end. (See Pl. 7.) To the north and east, high ridges of granite covered with bowlders of the same formation rise almost barren of vegetation above the belt of pine trees which forms a girdle about each of the parks, thus giving the ridges the appearance of projecting above timber line. A small stream flowing out of the lower end of the main La Grulla meadow by which we camped is said to form the extreme head of the Rio Santo Domingo. Near the lower pond in the meadow were two log cabins and a corral, where some Mexicans have a summer dairy camp and make cheese. They bring their cattle up from the foothills in spring, when the grass becomes green, and keep them until cold weather begins.

La Grulla has been visited by practically all naturalists who have been in these mountains, and between 1888 and 1893 A. W. Anthony was here several times. He found mallards and cinnamon teal nesting about the ponds in May, but at the time of our visit the borders of the ponds and all the valley bottom had been so closely grazed and trampled by cattle that no shelter was left for waterfowl, and not a duck was seen. Deer were common and remarkably unsuspicious near our camp. The trail from Vallecitos to La Grulla was so extremely steep and rocky in places that it was difficult to bring down the loaded pack animals, and an ascent would have been even more troublesome. A trail leading directly down the mountain from near our camp, at the lower end of La Grulla meadow, was reported to have some very difficult rocky slopes.

July 24 we completed our work at La Grulla and followed an old trail about 10 miles southeasterly along the mountain to Santa Rosa, another beautiful mountain park at about the same altitude (7,000 feet) as La Grulla. It is a waterless grassy valley like a shallow basin in form, about 2 by 3 miles in extent, and is bordered by low, pine-covered hills. This park occupies almost the entire breadth of the top of the mountain range. Santa Rosa Canyon heads on the northeastern side of the valley and leads thence directly down between high rocky walls to the desert at the east base of the range, draining to the gulf. An old trail dating back to the days of the early missionaries leads down this canyon and permanent water exists near its mouth. Mountain sheep frequent its rocky slopes and California condors are said to nest in holes in its high walls. The old trail from Santa Rosa Canyon crosses Santa Rosa Valley to the west side and then descends along the course of a small canyon. We left Santa Rosa by this trail, leading down to the west, and about 2 miles below came to a little benchlike valley in the canyon with a willow-bordered stream flowing along its middle. This is a southern tributary of the Rio Santo Domingo. The little valley had a house and a cattle corral at its upper end, known as the Rancho Santo Tomas, near which we camped several days at an altitude of about 6,000 feet. The owner has a small herd of cattle which he keeps here in summer. During our stay the carcass of a donkey in Santa Rosa Valley attracted about a dozen California condors, and we were able to secure two specimens. Others of these fine birds were seen, and they appeared to be rather common in this part of the mountains.

July 28 we left Rancho Santo Tomas and descended the west slope of the mountain by a well-worn trail. A few miles below the ranch we passed the ruins of the old San Pedro Martir Mission on a sloping bench on the mountain side, where a small stream afforded water for irrigating some small fields. All that now remains of the mission are the bases of adobe walls where the buildings stood, a little graveyard near, and the low banks of old irrigating ditches. About 16 miles below Santo Tomas we came to the bottom of the main slope of the mountain, where the stream-let we left above had increased to a swiftly flowing creek bordered by cottonwoods. From this point the trail turned northwesterly and after crossing several foothill ridges brought us to San Antonio ranch at an altitude of 2,000 feet on a main fork of the Santo Domingo River, where it emerges from its canyon in the west side of the main range. The ranch consists of two small houses occupied by a Mexican family. The stream at San Antonio at the time of our visit was 10 or 15 yards across and averaged less than a foot deep. Willows, cottonwoods, and small oaks fringe the water courses here. A species of rainbow trout which sometimes affords good fishing inhabits this stream from the ranch far up into the canyon. Our specimens proved this to be an undescribed species, which Dr. B. W. Evermann has named *Salmo nelsoni*. This is said to be the only stream containing trout in the peninsula, and is the only stream in Lower California which is reputed to maintain its flow to the sea along its entire course throughout the year. Another small stream from the mountain joins the San Antonio Creek a little below the ranch. The people at San Antonio ranch reported that trout were much less numerous than usual in 1905, owing to tremendous floods which had swept down the canyon the year before, carrying so many bowlders that many trout were killed.

Rancho San Antonio is in a narrow valley with the main San Pedro Martir Range rising to the east, while a high, narrow, outlying ridge attains an altitude of about 3,400 feet to the west and southwest. This latter mountain cuts off the moist coast winds and results in giving this valley a hot and much more arid climate than is usual west of this part of the main range.

On August 1 we left San Antonio for San Quintin on the Pacific coast. The trail crossed the valley and led directly up the high steep ridge to the west and then southwesterly down ridges and west-draining slopes for about 26 miles to our camp by a small stream at the upper end of the high-walled Canon de Nueva York, at an altitude of about 800 feet.

August 2 we continued our southwesterly course down low ridges and over sloping mesas west-draining for about 15 miles to the head of a broad, flat-bottomed, low-walled canyon, with a small stream at its head, down which we traveled for 5 miles to where it ended on the bare, nearly level coastal plain of San Quintin. Many California quail were seen near the water in the canyon.

In the lower part of the canyon we passed a number of old fenced fields and small board houses, and at its mouth several larger and more elaborate houses, water tanks, and wire fences, all showing evidence of having been abandoned for some years. We learned later that these were relics of an elaborate and costly but unsuccessful effort made by the Lower California Development Co. to establish a large agricultural colony on the coastal plain adjacent to San Quintin Bay. Five miles of travel from the mouth of the canyon across the nearly level plain brought us to San Quintin, at the head of the bay on the Pacific coast. A mile above the town, at the extreme head of the bay, was a large flour mill, built to grind the wheat the colonists were to produce, and extending from the mill a short distance northward on the plain was a scrap of railroad that was the beginning of a line planned to extend thence northward to southern California, to carry north the flour from the grain. San Quintin was the local headquarters of the colony, which extended for 10 miles or more up and down the coast. At the time of our visit the town contained a few wooden buildings, one of which was a combined hotel and store, the headquarters for occasional travelers and for the American and English miners engaged in prospecting to the southward. This place was a port of entry with a custom house and a total population of less than 50 people.

The coastal plain of San Quintin is from 2 to 6 miles broad and extends about 20 miles north and 15 or 18 miles south of the town, gradually narrowing near the extremes as the foothills approach the coast. The plain is rather sandy and overgrown with a small sparse vegetation of herbs and small shrubs. The land on a large part of the plain appears to be good, and well-directed dry farming methods might reclaim some of it. Some of the land is subirrigated, as was evidenced by several small growing cornfields among the deserted ranches in the canyon through which we entered the plain and the flourishing fig orchard we saw south of the San Simon River. No doubt there is also much underground water that might be made available by pumping. In addition reservoirs might be built in the foothills.

We worked for some days in the vicinity of San Quintin and packed and shipped our collections by the steamer *St. Denis*, which made regular round trips to this port from San Diego via Ensenada.

Early in the morning of August 12 we left San Quintin in the gasoline launch *Todos Santos* and soon after noon landed on a pretty sand beach on the northeastern shore of San Martin Island, north of the entrance to San Quintin Bay. On our way we noted that a narrow belt occupying the coast a short distance in both directions from the mouth of San Quintin Bay is volcanic and is dotted with numerous small volcanic hills. San Martin Island is a part of this belt and is wholly volcanic, the surface being made up of ragged and broken lava beds. It is a favorite nesting place for brown pelicans and cormorants and is one of the guano islands of this coast A few leopard seals and sea lions frequent its shores and the island was once a breeding resort for the sea elephant.

The morning of August 14 we left San Martin and ran down the coast to San Geronimo Island, where we arrived about 3 p. m. This small island is characterized by several small rounded hills. Gentle intervening slopes contained great numbers of deserted nesting burrows of shearwaters in which lived swarms of white-footed mice (*Peromyscus*). August 15 in a run of about eight hours we returned to San Quintin.

Between August 18 and 23 Goldman made a trip about 55 miles north to San Telmo to secure topotypes of some small mammals. From San Quintin his route followed the wagon road which extends north paralleling the coast to Ensenada and San Diego. About 25 miles north he reached the village of Santo Domingo, near the mouth of the river of the same name, and a mile or so below the ruins of the old Santo Domingo Mission. Several ranches are located here, including one owned by an American, Mr. Young, who was growing wheat, corn, peaches, grapes, melons, and other crops.

August 24 our recent collections were shipped by steamer to San Diego, and on August 25 we left San Quintin and traveled about 8 miles in a southeasterly course over the coast plain, crossing the broad dry bed of the San Simon River, near where it leaves the low foothills, and camped at the Santa Maria ranch, a short distance beyond, and about 3 miles from the sea.

This ranch belonged to Mr. Young, the American who has a place at Santo Domingo, and, although without surface irrigation, contains an orchard of large black fig trees several acres in extent. At the time of our visit the heavy crop of figs was being harvested as it ripened by hundreds of ravens which came down daily from the foothills. Fairly good crops of hay and grain are grown here, and the fig orchard and the eucalyptus trees bordering the fields show that there is abundant water near the surface for subirrigation. A number of deserted frame houses in this vicinity and an iron pipe line down the canyon of the San Simon River mark the failure of the San Quintin colonization efforts here. The Santa Maria and one or two adjoining ranches are the only occupied parts of the considerable area once colonized. Near the mouth of the San Simon River are some marshy areas, and adjacent flats overgrown with salt weeds.

August 31 we traveled south about 8 miles along the coast wagon road to Socorro, where there is a small fresh-water pond in the bottom of a wash which empties just below into a salt lagoon winding through a marshy flat. This part of the coast is bordered by a series of sand dunes backed by a long salt flat. The low rolling foothill plateau which backs the coast plain gradually approaches the shore from the north and reduces the plain to a narrow point, ending a little south of Socorro. Fogs are common along this part of the coast at this season.

September 1 we continued southward, the coast plain giving way to rolling hill country cut by many deep dry washes leading down to the sea from the interior, some of them broad enough to carry small rivers at flood time. About 10 miles south of Socorro the hills become so rough and broken near the coast that the road turns to the left up a broad canyon, and after crossing gently rolling hills and mesas for about 16 miles reaches the village of Rosario. This is a small place containing about 20 houses on the south bank of the Rosario River, some 5 miles above its mouth. (See Pl. 3, Fig. 2.) It is an unusually prosperous place, owing to its situation in a fertile little valley with a small permanent stream for irrigating fields in the level river bottom. Corn, wheat, barley, beans, figs, peaches, almonds, and a few other crops are produced here. The Rosario River rises in the dry river bed a short distance above the village and is one of the very few streams of the peninsula which are said nearly to reach the sea throughout the year. The surrounding hills, especially inland, are so barren and clayey that they form a kind of "badlands."

September 2. The wagon road ended at Rosario and a trail led in a general easterly course from the village up a long dry arroyo among low, barren, rolling hills, and then across hilly plateau country, which gradually rises until, about 25 miles inland, we reached a large shelter cave in the rocks on the side of a canyon where we camped. This is a regular camping place known as Las Cuevas and has an altitude of about 1,500 feet. Close by, in some deep potholes in the bottom of the dry rocky canyon, are large tanks or tinajas of good water. A few miles from Rosario the barren clay hills change to a more rocky formation with more abundant desert vegetation. About 8 miles out on the trail we saw the first giant cactuses (*Pachycereus pringlei*), and 18 miles out, on the top of a mesa, at about 2,000 feet altitude, appeared the first of the singular, polelike tree (*Idria columnaris*) called cirio by the Mexicans. Both of these plants became more common as we advanced.

September 3 the trail led easterly from Las Cuevas through an elevated rolling and rocky plain, broken by low rounded hills and isolated mountains with occasional small valleys. All along the trail we were amid a plentiful growth of the strange cirio, giant cactus, ocotillo (*Fouquieria splendens*), and other desert plants—a striking contrast to the scanty vegetation on the barren hills a few miles nearer the coast. (See Pl. 29, Fig. 1.) Fifteen miles easterly from Las Cuevas we came to San Fernando, the site of one of the early missions, now marked by the ruined walls of the old buildings, some old irrigating ditches, and a little cluster of adobe houses sheltering two or three poverty-stricken Mexican families. San Fernando is situated at an altitude of about 1,500 feet on the side of a narrow valley marking the course of the San Fernando River. The bed of the stream is dry throughout most of its course, except at flood times, but at San Fernando some large springs furnish permanent water for irrigating small fields. The lines of the irrigating canals built by the missionaries show that in their day several hundred acres of land must have been irrigated. The old ditches were well made,

Giant cactus (*Pachycereus pringlei*) on road from Santo Domingo Landing to Calmalli. The trunk of this giant of its kind was about 3 feet in diameter and the whole tree was 60 feet high.

FIG. 1.—The Llano de los Buenos Aires, a part of the great interior plateau south of the onyx mine. Note flat-topped hills showing former surface level, sloping gently to the Pacific coast.

FIG. 2.—San Pablo Canyon below ruins of old mission. This canyon is cut in the great lava-capped plateau, the basal sandstone showing in wall.

extend along both sides of the valley, and in some places were built up 8 or 10 feet with stones. More than a century ago this was a populous and well-cultivated little valley, where cotton and many other crops were grown, but it has now returned almost to its primitive condition, only a few acres being under tillage. From the size and length of the ditches water must formerly have been much more abundant than now. We remained here two days collecting among the willows about the water and on the adjacent arid hillsides. A number of copper mines have been prospected and abandoned here.

September 6 we continued our journey, following a wagon road easterly from San Fernando up the valley, which soon broadens to an open plain called the Llano de Buenos Aires or Llano de San Augustin. After traveling about 20 miles we reached Poso San Augustin at an altitude of 1,800 feet, where the wagon road we followed joins the main wagon road over which onyx is hauled from the mine to Santa Catarina Landing on the Pacific coast for shipment to California. A well had been dug at San Augustin to a depth of about 50 feet beside a sandy dry wash in the open plain and contained a good supply of water.

September 7 we traveled 11 miles easterly across the plain on a good wagon road to the onyx mines which are located at 2,500 feet altitude on the edge of the low foothills skirting the mountains which rise abruptly a little farther eastward toward the Gulf coast. The onyx mines, then being worked by a San Diego company, are near the upper end of El Tule Arroyo, which leads easterly through the mountains to the gulf. The location of the mines was formerly called El Tule but has been changed to Onyx. The camp consists of a small store and a few small houses for employees built on the bare open slope. The onyx is in horizontal beds in limestone near the surface.

September 8 we left the wagon road at Onyx and turned southward on a trail across a low ridge and then over a gently rolling desert plain for 8 miles to a water hole known as Agua Dulce, situated in the head of a rocky canyon which begins abruptly in the limestone bedrock of a little valley on the open plain. An abruptly rising, barren range of mountain walls in the eastern side of the Llano de los Buenos Aires, extends parallel to the Gulf coast far to the southeastward beyond Agua Dulce. (See Pl. 9, Fig. 1.)

September 9 we traveled rapidly southeasterly on an old trail leading across a gently undulating plateau of decomposed granitic soil, over which were scattered low ridges, great piles of gigantic bowlders, or single bowlders of pale granite. This granite is the same in appearance as that on the Sierra Juarez and San Pedro Martir Mountains. The general altitude of the plateau was about 2,000 feet, and to the east and west lie distant ranges of mountains. The vegetation on this granitic plateau country was a wonderful combination of desert species, among the most conspicuous of which were *Idria columnaris*, *Fouquieria splendens*, *Pachycormus discolor*, *Pachycereus pringlei*, and several other cactuses, yuccas, agaves, the creosote bush, and others.

Eighteen miles from Agua Dulce we came suddenly to the Arroyo de Cataviña, a beautiful open, shallow canyon winding through the desert. (See Pl. 27.) Most of the broad sandy wash in the bottom was dry, but thin patches of green grass and willows and numerous tall and graceful fan palms were scattered along its course. These showed the presence of water close to the surface, and where the trail crosses the canyon a small stream rises and flows on the surface a short distance. At this point the wonderfully picturesque combination of fan palms, cirio, giant cactuses, agaves, and yuccas made a landscape suggesting the strange plant life of some remote geological period and is probably unequaled elsewhere in America. From here we continued in a southeasterly course for about 12 miles to the Arroyo de Jaraguay.

As soon as we crossed Cataviña, the formation of the country became more broken and was made up mainly of volcanic rock, though ridges of granite continued to outcrop here and there. The Arroyo de Jaraguay, like that of Cataviña, occupies a low, open canyon winding across the plain, but is larger, the broad sandy wash appearing like a white river bed. Many large groups of fan palms were growing along the Arroyo. We reached Arroyo de Jaraguay at sunset and searched the sandy bed for water without success until after dark, when we discovered it in two holes, 2 or 3 feet deep, dug by coyotes. The water had been visited by coyotes and buzzards

until it was very foul, but we were forced to use it. The drainage throughout the country traversed from Onyx to this point is into the Pacific.

September 10 we continued about 9 miles southeasterly across the same plateau country to a curious high isolated hill of huge granite bowlders measuring 2 to 10 feet in diameter, which stands on an oval, nearly flat-bottomed little basin a couple of miles in diameter. This hill, aptly named the Cerro Pedregoso, is a well-known landmark on this trail. Another trail, apparently the main traveled route, came in from the west and joined ours close to Cerro Pedregoso. This is the direct trail from San Fernando by way of some small mining camps and continues south down the middle of the peninsula. About 4 miles beyond Cerro Pedregoso, along the main trail which leads through a series of basinlike flats, we stopped at midday under a group of mesquites. At this point a dim trail branched off to the left, and we followed it for about 8 miles over gently rolling hills to the crest of the slope, which at an elevation of 2,800 feet forms the peninsular divide at this point. From the top of the divide an abrupt descent on the east leads to a lower plain extending to the shore of the gulf, which was in plain view from the divide. From near Jaraguay to the crest of this ridge, owing to a change in the geological formation, the abundant vegetation noted along yesterday's route gave way to a scanty herbage and few shrubs.

A good trail leads from the divide down the east slope to a small, strongly mineralized stream flowing through a series of pools in the smooth rock bottom of a broad canyon. Thence the canyon narrowed and, after leaving it and crossing some low hills, we reached the barren valley in the plain along which the San Francisquito wash finds its way. We camped on the east side of the wash, about 8 miles from the top of the divide and at an altitude of 1,400 feet. Here a well, some old arrastras, and many other signs marked the site of the long-deserted placer mining camp of San Francisquito. An old wagon road led away from the arrastras toward the gulf, whence supplies must have been brought. A sloping plain, broken irregularly by low hills and mountains, probably all below 2,000 feet altitude, extends north and south from this place and is known as the Llano de San Francisco, or Llano de Santa Maria. Toward the gulf the plain is broken by low ranges of hills, while on the west rise the steep escarpments of the main divide we had crossed.

Conditions were extremely arid at San Francisquito and the vegetation was much like that about San Felipe Bay. The San Francisquito wells are strongly mineralized and the water is very bad, but 6 miles southerly, in the upper end of a bare granite canyon, are small pools of fine pure water. This is the source of supply for the King Richard mine mentioned below, and a wagon road leads from near this water easterly across the plain to the mine. Two Mexican families employed by the mine were living in brush huts at these water holes.

Practically throughout this expedition our stock was forced to depend for food on the plants growing on the desert, and edible species were often extremely scarce. By the time we reached San Francisquito the animals were so worn down we were obliged to rest several days. It was extremely hot here, and in order to save the stock as much as possible we broke camp September 13 at 4 a. m. in brilliant moonlight and traveled 10 miles easterly, following the wagon road from the water canyon across the plain and down a low-walled canyon leading toward the gulf, to the King Richard mine. This is a gold mine worked by an Englishman named Dick Daggett. To our surprise the camp was deserted, every house was locked, and there were no signs of recent occupation. This left us in a serious position, for we had less than a pound of flour and no beans, rice, sugar, or bacon, and were many days' travel from any supply point. We had seen Daggett several weeks before at San Quintin, and he had agreed to sell us provisions, if needed, and it became necessary to find him or face a trip of several hundred miles to the next supply point, subsisting on such small game as we might shoot. Several used trails radiated in various directions from the camp, one leading down the canyon toward the gulf showing the most recent tracks. We followed this for about 6 miles, through a series of small canyons and over dividing ridges in a broken granitic and slate hill country and came out into the broad, gently sloping Calamahue Valley, through which a dry rocky wash, like a broad river bed, wound its way. The trail led us thence down the valley about 9 miles to the mouth of the wash, where it passes through a narrow gap between two

low ridges of hills and reaches the gulf at a point on the shore known as Calamahue Landing. This is one of several places along the gulf coast where supplies ordered from Guaymas, Sonora, are occasionally landed for mining companies. We were much relieved to find a group of small brush huts by a shallow well at the base of the hill on the right of the gap, where Daggett and his miners were camped. Daggett welcomed us hospitably and said that through a misunderstanding his supplies failed to arrive on time from Guaymas and he and his men were forced to close the mine, come down to this point, and subsist for more than a month solely on sea turtle and fish caught in the gulf. Fortunately for us the night before our arrival the boat had come in and the supplies were lying on the open beach at the mouth of the wash. Daggett told me that he and his Indian miners had been living for two weeks on fish they managed to catch along shore and wild honey from the rocky hillsides.

Daggett kindly sold us the necessary provisions, and we turned back up the valley about 3 miles and made a dry camp. The day was extremely hot, and as we traveled up the smooth sandy flat, just after sunset, we saw two "side-winder" rattlesnakes lying in the warm dust of the trail. On our approach they slid diagonally sidewise and forward about 15 feet to one side of the trail. There they stopped and sounded their low warning rattles as each animal of our outfit passed.

There was scarcely a shred of feed either at Daggett's, or where we camped, and for the salvation of our animals it was necessary to find pasturage. The moon was shining brilliantly after midnight and, in order to reach a place where the stock could find feed and to travel as little as possible in the intense heat of the sun, we resumed our journey at 2 a. m., September 14. At 10.30 a. m., after traveling 19 miles, we reached the upper end of the valley, where it closes into the mouth of a narrow canyon. Just inside the mouth of the canyon several springs and pools feed a small permanent stream, which sinks a short distance below. The water in the springs is charged with varying amounts of soda, iron, and other minerals, and most of it is undrinkable. Large gas bubbles were rising in one spring about which deposits of soda had built up a broad rim several feet high. On the southern side of the mouth of the canyon are the ruined walls of the old Calamahue Mission. This was one of the most desolate and trying camps we made and we marveled at the old missionary padres who would choose such a place to build a mission.

All along its upper half Calamahue Valley is crossed from south to north by well-marked old trails, made by mountain sheep, leading from the projecting points of the Calamahue Mountains to opposite points of the lower range of hills on the north. In places the sheep must have traveled several miles across the flat valley bottom. The small scanty vegetation and the generally barren character of the hills and plain about San Francisquito, and also in Calamahue Valley, and the bordering mountains closely resemble conditions prevailing near San Felipe Bay and contrast strongly with the greater abundance of vegetation in most of the country west of the peninsular divide. A scattered growth of small trees, either pinyon pines or live oaks, was visible on the upper 500 or more feet of the northerly slopes of the Calamahue Mountains, a few miles southeasterly from the mouth of the canyon. This is the first tree growth we had noted on the mountains south of the San Pedro Martir Range and we should have investigated it if our saddle and pack animals had not been too exhausted to permit delay owing to the scanty feed along this part of the route.

We remained two days at Calamahue to rest the animals. It was excessively hot and each day a strong wind blew down the canyon which seemed to come directly from a furnace. Guns or other iron objects left for a short time in the sun became too hot to handle. The intense heat, high winds, and bad water at this place made it such an unpleasant camp that on September 16 we were glad to move on. The route leads up the canyon, which has high rocky walls along most of its course. Water comes to the surface at several points along the bottom, and 5 miles above its mouth, near the head of the canyon, we came to the last water, a spring charged with alkali and iron, but usable. Here we stopped during the middle of the day under the shade of some mesquite bushes. On our way up the canyon we saw mountain sheep tracks at places in the bottom and one fine old ram came out on the sky line of a high rocky point about 500

yards away and gazed down as we filed by. I should have been glad to stop at this promising hunting ground, but our saddle and pack animals were becoming too weak to risk the delay.

The Calamahue Mountains, through which this canyon cuts its way, are rarely visited by anyone and sheep are probably numerous in them. Birds were scarce from the plain at San Francisquito to Calamahue, but there were many signs of small desert mammals, such as *Dipodomys*, *Perognathus*, and *Peromyscus*, and jack rabbits were numerous in the upper end of Calamahue Valley.

From the upper spring in Calamahue Canyon the trail led to the head of the gently rising canyon and out on the eastern border of a part of the broad interior tableland known as the Llano de Santa Ana. The surface of the great central tableland is depressed at the head of Calamahue Canyon to an altitude of about 1,200 feet, thus forming one of the lowest passes between the east and west coasts in the entire peninsula. The plain is broken only by low scattered hills and ridges and is bordered along its eastern side by the Calamahue Mountains, through a low gap of which we had just come, and far to the west and southwest by several low mountain ridges, including the Sierra Columbia, a sharp-ridged range lying nearly parallel to and not far from the Pacific coast. From its eastern border the plain slopes gently 10 or 15 miles southwesterly to the head of the long San Andres Valley, which lies along the east base of the Sierra Columbia Mountains and drains southerly into the Pacific.

Along Calamahue Valley and Canyon were thinly scattered mesquites, acacias, the garambullo cactus, elephant wood, *Fouquieria*, *Cercidium*, *Covillea*, *Opuntia bigelovii*, and a few other species, but immediately after passing over the Pacific slope divide to the Llano de Santa Ana we came into a granitic country again and found a wonderfully vigorous growth of desert vegetation, including the species named above, yuccas, and numerous others extending across the plain as far as we could see, and in many places forming impenetrable thorny jungles.

Soon after we reached the Llano de Santa Ana the sun set in gorgeous colors, and a little later the moonlight enabled us to continue southeasterly about 23 miles from our noon camp, through a strange forest of desert plants. About 10 o'clock the trail became too dim to follow and we camped in an open space at 2,200 feet altitude. The horses and mules were hobbled and turned loose to search for food, while we made a fire and after a hasty meal unrolled our blankets and slept, as usual, under the brilliantly starlit sky.

September 17 we made an early start from our dry camp and continued 10 miles across the rolling plain, which reached an altitude of 2,500 feet and became more broken and rocky before we reached the tinaja or water hole of Yubay. This is a large pothole of rain water 15 or 18 feet across and several feet deep in the bed rock at the mouth of a small canyon which leads through a bare granite ridge rising about 500 feet immediately northeast of Yubay. This is one of a scattered series of ridges which extend for miles along the easterly side of this part of the tableland from near the head of Calamahue Canyon to a point considerably southeast of Yubay.

San Andres Valley to the westward was full of fog on the morning of September 17, and at daybreak on the 18th the fog covered the country at least to 2,500 feet altitude on the granite ridges back of camp. At sunrise the vegetation was dripping and the entire surface of the ground was wet from the fog, but by 8 o'clock had become completely dry. These fogs must be of material help in carrying vegetation through long rainless periods. At this time the days were very hot throughout this section of the peninsula, but the nights toward morning so cool that we needed heavy blankets.

From Yubay the trail continues southward along the middle of the peninsula by way of the old mission of San Borja, and we had been informed that it was 50 miles to the nearest water in that direction. To attempt to travel this distance without water with our worn-out stock would be extremely hazardous, and I decided to leave the trail here and strike directly across country to San Andres, a deserted ranch near the Pacific coast, in the lower end of the San Andres Valley, where it was reported we could find water nearer than on the regular route. We accordingly left Yubay early in the afternoon of September 19 and traveled until after dark. Our course was southwesterly down the sloping and slightly rolling plain, which is cut

FIG. 1.—Summit of lava-capped plateau near the Tinaja de Santa Ana, north of San Ignacio.

into mesa sections by a series of parallel dry canyons 50 to 75 feet deep extending down the slope. Several miles below Yubay the sloping plain becomes more broken and rocky and ends on the border of San Andres Valley. The bottom of this valley opposite Yubay has a width of 6 to 8 miles westerly to the base of the barren Columbia or Prieta Range, which forms one of the series of small ranges already mentioned as extending parallel to the west coast. The valley has a southerly course, and a broad, stony dry wash like a river bed winds down its bottom, draining this section of the peninsula, including the Llano de Santa Ana, into Playa Maria Bay.

All down the slope from Yubay we traversed a jungle of giant and other cactuses, yuccas, agaves, copal, paloverde, elephant wood, the tall columnar cirio, ocotillo, and many other desert species. In the bottom of the valley this growth became extraordinarily vigorous and formed a veritable forest, which over considerable areas was absolutely impenetrable. Fortunately these areas of dense growth were irregular in outline and varied by narrow open spaces, through which we were able with much difficulty to make our way. We were repeatedly forced to turn back and try a new route. Just at dark we crossed the broad dry wash in the bottom of the valley and came into a well-marked and recently traveled trail leading down the west side of the valley—the west coast trail. We were much pleased to escape from the untrodden cactus forest, and turning southward continued until it became too dark to distinguish the trail. We then made a dry camp, 20 miles from Yubay, at an altitude of about 1,000 feet, in a small open place beside the trail, the light from a group of dry yuccas we set on fire making a fine illumination for half an hour.

The darkness became less intense after midnight, and in order to make the journey as easy as possible for the stock by traveling in the cool early morning hours, we broke camp at 2 a. m. and continued down the trail. After traveling about 10 miles we reached Punta Prieta, a deserted cattle ranch. This place had been occupied within a few weeks and we were glad to find a well about 40 feet deep with a bucket and rope, so we were able to water our stock. Thence we continued about 10 miles farther down the trail to San Andres Ranch, at the extreme lower end of the valley. Here the hills on both sides shut in and reduce the valley to a narrow point from which a short canyon leads through the coast hills to the shore of Playa Maria Bay. About a mile of the lower end of the valley had been extensively improved and the ruins of well-made houses, machinery, good wells, irrigation ditches, and old fields showed that a large amount of money had been spent here, but the project had evidently been a complete failure and from the ruined condition of the improvements it was plain the place had been abandoned for many years.

I have since learned that this establishment belonged to an English corporation (Henry Louis & Co.), which was operating here in 1887 with the object of making paper from the datilillo or yucca (*Yucca valida*), which abounds throughout this region.[1]

At the extreme lower end of the valley water lies near enough the surface to make some wet meadows and to fill a small pond. The green flats and large mesquites gave a welcome change from the desert country we had traversed, and a short stop was made here to rest the stock. An ocotillo we had not seen before (*Fouquieria peninsularis*) grew in the valley above San Andres and *Idria columnaris* was abundant in the valley just above the ranch. Harris's hawk, Scott's oriole, and the black-chinned sparrow (*Spizella atrogularis*), were common here. A dozen or more Harris's hawks, a species which had not been seen since we left Ensenada, gathered every day at sunset to roost in the tall cirios near the ranch.

September 24 we continued our journey along the coast trail in an east-of-south course a short distance inland, crossing low ranges of coast hills cut at frequent intervals by deep, rocky, dry watercourses, all nearly parallel and leading to the sea. In a small open canyon 8 miles from San Andres we passed a brackish water hole called San Dominguito. About 10 miles beyond this we came to another broad, flat-bottomed valley, which narrows abruptly between hills at the lower end, bringing underground water to the surface in wet meadows and draining thence into Santa Rosalia Bay through a short canyon, thus almost duplicating the

[1] See Lopatecki in West American Scientist, pp. 129, 130, May, 1887.

situation at San Andres Valley. This is Rosarito Valley, and from the appearance of its lower end it was evident that during rainy years there are large swampy flats here, but we found water only in a single small hole. We camped on the right-hand side near the lower end of the valley, by the ruins of several large buildings, about which parts of machinery were scattered. Here, years ago, unsuccessful efforts were made to extract the fiber from a large species of agave, which is common on the hills of this section. The coast hills here are covered with a scattered growth of agaves, yuccas, ocotillo (*Fouquieria peninsularis*), cirio, elephant wood, creosote bush, and several species of cactus. The growth is smaller and stunted on the hill slopes, and much more vigorous and abundant in the bottoms of the numerous broad canyons and small valleys. Since leaving the San Pedro Martir Mountains we had had unbroken sunshine, but to-day local showers from large cumulus clouds were seen to the east and south.

September 25 our trail led southeasterly through the coast hills about 8 miles to San Javier Canyon, striking it a few miles above the sea. Where we entered San Javier Wash it forms a narrow valley, soon closing in to a canyon bordered by low sandstone walls, down which the trail led for some distance. At first we found a series of fine water holes scattered along the bottom, but they were soon replaced by a clear stream of excellent water, which flowed about a mile before it was again lost in the sand. Below this the trail passed out of the canyon for about 5 miles through the coast hills and then descended near the seashore to the northern point of the Santo Domingo Plain. From this point southward the coast hills and low mountains swing inland, the nearly level plain extending along the coast and broadening southeasterly into the Vizcaino Desert. Near where we entered the northern end of the plain, the shore is bordered by a broad belt of high sand dunes lying immediately back of the beach. On the inland side they are succeeded by a nearly level area 4 or 5 miles broad to the base of series of rugged, scattered hills and ridges. Farther south, 2 to 3 miles back of the shore, a tree-yucca forest extends over the plain for miles, sparsely intermingled with *Fouquieria* and other large scattered shrubs on which a heavy growth of orchilla (*Roccella*) was hanging. (See Pl. 29, Fig. 2, and pl. 30, fig. 1.) Soon after entering the plain we saw traces of a wagon road, which skirts the coast from the landing at Santa Rosalia Bay southeasterly to Santo Domingo. We followed it for about 9 miles on the flat, well back of the sand dunes, until sunset, when we made camp about a mile from the sea, with no water and very little grazing.

September 26 the road led down the plain 8 miles from our camp, then crossed the dunes and skirted the shore of Santo Domingo Lagoon about 5 miles to the little group of houses at Santo Domingo Landing, where the customs inspector lives. This is the place where supplies are landed on the open beach for the interior gold mining camps of Calmalli and Campo Aleman. A wagon road leads from the landing a little north of east across the plain to these camps. We followed it for 3 miles to a well at the foot of the escarpment of a mesa fronting the coast, where the plain rises abruptly about 50 feet. Close by, on top of the border of the mesa, was a small house, also a corral containing a shed where we camped. The well and buildings here are for the use of freighters hauling supplies to the mining camps. This well is the only water supply for the customs people, as there is none near shore at the landing. When we arrived at the well our horses and mules had been without water for 24 hours and showed such signs of exhaustion that we stopped here a day for their benefit. The scanty forage all along our route made the journey hard for our animals, thus rendering it necessary to watch them closely and to stop at intervals to permit them to rest and regain their strength. Without such care we could not have made half of the journey.

The type locality of the desert thrasher (*Toxostoma lecontei arenicola*) is near where we first heard its notes in the sand dunes when we approached them north of Santo Domingo Landing. It was abundant between the landing and the well, and in early morning and near sunset its beautiful song was heard on all sides.

September 28 we took a cut-off trail easterly through the yucca forest, the wagon road making a wide detour to the south. The trail led over a sandy plain through an unbroken forest of yuccas intermingled with *Fouquieria peninsularis*, which had been plentiful since we entered its range near San Andres. The yuccas had their tops all inclined toward the southeast owing to the

prevalence of northwest trade winds. Nine miles from camp we came into the wagon road again beside a deserted frame house and broken windmill over a dry well. This was the Rancho de Berrendo, situated on the border of the Llano de Berrendo, an open, clayey prairie 4 or 5 miles across with a dwarf chamiso almost the only plant growing on it. The sandy soil and the yucca forest stopped abruptly on the border of this prairie, but began again beyond it to the east. The plain rises very gradually inland, and about 20 miles from the coast the soil becomes less sandy and the yucca forest gives way to a more mixed growth of yuccas, ocotillo (*Fouquieria peninsularis*), many giant cactuses, including the largest specimens of the latter we had ever seen, and many other species. We traveled until long after dark, and at 9.30 p. m., at an altitude of 850 feet, reached a solitary hill known as the Cerro Perdido, about 25 miles from our camp at Santo Domingo. This is one of the regular camping places on this road, but there was no water, so we were compelled to make another dry camp, which was hard for the stock.

September 29 we made an early start and a mile beyond camp came to another abrupt escarpment about 50 feet high, capped by a plateau extending away eastward into the interior. Before us to our left a range of hills approached our course diagonally from the northwest, while far away to the east low mountains, some rising to an altitude of from 3,000 to 4,000 feet, stood out boldly. About 10 miles east of this last escarpment the road led us through a range of low detached mountains or hills about a mile wide and 5 miles long. The hills rise abruptly and island like from the level plain, and from their relative position and formation it was evident that they represented the tops of a short, partly buried mountain range. About 4 miles beyond the road led through another group of hills, turned to the south, and at an altitude of 1,200 feet came to the mining town of Calmalli. This is located on the foot of a group of low bare hills and contained 25 or 30 small houses, two or three stores, and the reduction works for the mines.

Extensive gold placers were discovered at Calmalli in 1883 from which, during the next few years, over $3,000,000 were taken. The placers were long ago worked out and at the time of our visit the town was nearly deserted. A quartz mine nearby was being worked in a small way by an American, Mr. Byron Hall, who received us hospitably.

Good trails lead from Calmalli easterly to Barril Landing, and to San Rafael, on the gulf coast. The trail passes over a divide on the mountains at an altitude of about 2,500 feet. Barril Landing is the point where supplies are landed from Guaymas. They are then packed on mules and donkeys across the mountains to Calmalli.

The wagon road from our camp at Cerro Perdido at first led through the same strong growth of desert plants noted the previous day, but near Calmalli the country became more sterile and the cirio, which we had not seen nearer the coast, appeared again. The plain extending inland from Santo Domingo reaches its eastern limit a few miles east of Calmalli, where ranges of barren rocky mountains rise abruptly from the general level and form a barrier. Immediately about Calmalli, especially to the west and south, rise low round-topped barren hills or small mountains.

October 1, we left Calmalli and followed a continuation of the wagon road about 5 miles southerly through the low mountains to the still smaller mining camp of Campo Aleman, where another mine was being worked on a small scale. At both camps water was obtained from wells in the bottoms of gulches. The hills from Calmalli to beyond Campo Aleman contain much slate with some quartz and show many signs of former placer mining. Two or three miles beyond Campo Aleman the road led down from the hills to the lower northeastern extension of the Vizcaino Desert plain, which extends to the base of the mountains a few miles east of our route and west to the coast about Scammon Lagoon. We made a dry camp on the plain, at an altitude of 500 feet, about 14 miles south of Calmalli.

October 2, about 16 miles southeasterly across the plain, we came to Poso Altamirano, a small cattle ranch at an altitude of 400 feet on the bank of an arroyo where a shallow well in the granitic sand of the wash gave a good supply of fine water. A few miles northeasterly across the plain from this point the light-colored granite mountains, which are practically continuous from the California border to this point, end abruptly and are replaced thence southerly along the backbone of the peninsula to La Paz Bay by black, lava-covered mountains and

plateaus. The northern foothills of these lava mountains begin about a mile south of Poso Altamirano.

October 3 we traveled about 3 miles southwesterly from Poso Altamirano and rounding a point of the mountainous plateau entered the mouth of San Pablo Canyon. The western border of this mountain plateau rises abruptly from the Vizcaino Desert, and the lower part of the canyon, which has its head far back in the range, is broad and gently sloping with a dry, sandy wash which evidently at times carries great volumes of flood waters winding down its bottom and thence across the plain toward the sea. We ascended the canyon between increasingly high walls of black lava, underlaid by horizontal beds of sandstone, for about 12 miles, until it narrowed to a width of a few hundred yards, with a high bench along its southern side. Here we camped near the lower end of a small stream of clear water just above the point where it sinks in the sandy wash. A short distance above, close to the ruins of the San Pablo Mission, was a small ranch occupied by a Mexican family. A few acres of land are still in cultivation below the irrigating ditches built long ago by the missionaries. The old mission has an altitude of about 1,000 feet and is in an extremely hot location, the effect of the sun being intensified by the heat stored in the black lava walls of the canyon, which immediately above the ranch close in and form a deep box canyon. A vigorous growth of large cactuses and other desert vegetation occupies the bottom of the canyon about our camping place, and a few fan palms were growing at the ranch. The water and abundant vegetation near the old mission made an attractive place for birds and we saw here the first representatives of such cape district species as the cape cardinal and cape house finch. What was still more surprising was the discovery among the cactuses at this camp of a previously unknown chipmunk (*Eutamias merriami meridionalis*). We had seen no relative of this species since leaving the pine forests on the upper slopes of the San Pedro Martir Mountains. Its presence here appears to indicate that the species formerly ranged continuously at least thus far south but has become extinct elsewhere.

This was a promising locality to work, but cattle had eaten the feed so closely there was nothing for our stock and we were forced, much to our regret, to continue our journey the next day, October 4. The trail turned southerly across the bench near the lower end of the water and then zigzagged directly up the steep canyon side for over 1,000 feet. This brought us out on the top of the west slope of a great lava plateau with a broad undulating surface rising toward the east, broken here and there by scattered volcanic hills, and descending on the west to the Vizcaino Desert. This plateau country is made up of horizontal beds of sandstone capped by heavy beds of dark lava. The scanty soil supports only a thin growth of vegetation, as most of the surface is covered by an almost continuous layer, and sometimes deep beds, of loose fragments of lava, which give a desolate and forbidding appearance to the landscape. This excessively stony plateau is cut by numerous shallow gulches and occasional deep canyons, all draining westerly into the desert. Travel through this endless bed of loose stones was very difficult for our animals. The trail wound along the top of the mesa, crossing a number of the larger canyons, one of which was about 2,000 feet deep.

Seven miles southerly from San Pablo on top of the undulating plateau, at an altitude of 3,400 feet, we reached a small house and corral with a large natural tank of water in the bottom of a lava-bedded gulch near by. This place, known as Santa Ana, is occupied as a cattle ranch part of the year but was vacant at the time of our visit. From the crest of a small ridge here an extended view, as far as the eye could reach northwest and southeast over the top of the plateau, showed series of volcanic ridges and peaks breaking its surface irregularly. To the west was a superb view over the Vizcaino Desert to the Sierra Pintada and Sierra Santa Clara, the salt beds at Ojo de Liebre, the old whaling location of Scammon Lagoon, and across the Pacific to Cedros and other coast islands.

October 5 the trail continued southeasterly over the lava plateau, crossing several canyons and gradually swinging down toward its western border. About 10 miles from Santa Ana we came to a large rock tank, the Tinaja de San Esteban, at an altitude of 1,200 feet in the bottom of a small gulch only a few miles from the eastern border of the Vizcaino Desert. Near this point we saw the southernmost representatives of the cirio (*Idria columnaris*) and the first

FIG. 1.—San Ignacio in 1905. The old mission church stands in the background. Many small houses shown on the flat were destroyed by a flood in 1911.

FIG. 2.—Wilderness at Mission San Angel on arroyo of Vizcaino Desert, about 30 miles west of San Ignacio. Salt grass, Distichlis palmeri, are numerous there.

FIG. 1.—Ojo de Liebre, or Jack Rabbit Spring, near head of Scammon Lagoon, on Vizcaino Desert. This spring is the only water within a day's journey in any direction and is marked by two stunted cottonwood trees which are visible only a short distance owing to surrounding sand dunes.

FIG. 2.—Sea turtle corral at Scammon Lagoon. Sea turtles abound in Scammon Lagoon, where they are being taken and shipped by a weekly schooner to San Diego. About 1,000 turtles a month are shipped from this point.

(Photographs from Capt. H. W. Cochran, U. S. A.)

northerly representative of the white barked palo blanco, which was abundant in the bottoms of the larger canyons. A few other plants, mainly tropical or subtropical species not noted before, were first observed along the canyons crossed to-day. Five miles beyond San Esteban, across an intervening lava mesa, we came to La Natividad, a large canyon in which water usually exists. The bottoms of the empty tanks were still damp but no water could be found, so we were forced to make another dry camp.

October 6 the trail led southeasterly about 20 miles to San Ignacio. This part of the route crossed a lower and more undulating part of the plateau, which was even more rocky than the sections we had passed, being characterized by numerous extended beds of large angular fragments of lava, sometimes a mile or more broad, over which the animals had to pick their way slowly and with great caution to avoid falling. Some of these lava beds were made up of rough fragments 1 to 3 feet in diameter, and it would have been impossible to cross them with animals but for the work done by the Indians under direction of the early Spanish missionaries in clearing the trail for several miles. These made trails are parts of the old Camino Real, or Royal Highway, or main road, which united some of the missions in early days. After covering about 12 miles of this excessively trying road we came to better traveling, and 2 miles beyond reached a narrow tank more than 100 yards long full of water, called the Tinaja de San Juan, situated in the lava bottom of a small gulch. A wild fig tree grew on one side of the tank and several coots (*Fulica*) were at home there despite the bare lava borders to the water. Five miles beyond we rode out on the brow of the mesa overlooking the valley of San Ignacio and saw the village among the date palms a mile away on the opposite side. At this point a horse ridden by one of our camp men became too exhausted to go farther. Its saddle was placed on one of the pack mules and the animal left to rest for a day before it was brought into camp. We continued up the valley and camped by a great spring just above the town. This is one of several springs rising in the flat bottom of the valley which supply the water used in irrigating the palms and other cultivated crops. Below the springs are several ponds surrounded with tules and bushes.

San Ignacio Mission was established in 1728 and has been continuously occupied from that date. (See Pl. 11, Fig. 1.) Soon after 1730 three kinds of Arabian date palms were introduced and to-day it is estimated that there are from 50,000 to 60,000 trees in this valley. They form a small forest about the town and thence down the valley for several miles and render this one of the most beautiful oases in all the peninsula. About 50,000 pounds of dried dates are sent to Santa Rosalia on the gulf coast each year. Ravens and Gila woodpeckers destroy the ripening dates by day and the bassarisk, or ring-tailed cat, by night, thus doing considerable damage. Many gray foxes and striped skunks have their dens in the rocky walls of the canyon and come into the palm groves at night to pick up the fallen fruit.

In addition to the date palms various crops and fruits are cultivated on a small scale, including oranges, lemons, pomegranates, olives, figs, grapes, sugar cane, corn, beans, and others.

San Ignacio is situated at an altitude of 500 feet, and at the time of our visit contained about 800 inhabitants. It is one of the most fertile and populous oases in the peninsula. The old mission church and the adobe houses of the principal inhabitants are on the basal slope under the lava cliffs forming the south side of the valley, but most of the people live in thatched huts scattered amid the date palms in the lowest part of the bottom among drainage channels where flood waters pass. Above the town the remains of a well-made earthen dike extends from the south side in a curve across more than half the width of the valley and then down on the north side. This was built by the Indians under the direction of the Spanish missionaries to turn flood waters out of their old channels and around the north side of town, thus protecting the fields and houses located in the original drainage way. Long ago a heavy flood broke through the dike and drowned some of the people, since which the survivors and their descendants, lacking the energetic direction of the missionaries, have never had sufficient energy to

repair the break. The dike is 4 to 10 feet high with the convex curve up the valley, and with the points where it crosses drainage channels faced up with rubble.[1]

We were informed that this locality sometimes suffers from prolonged droughts covering several successive years, during which the large springs continue to flow steadily but with somewhat lessened volume. The abundant water and attendant plant life at San Ignacio render this an exceptionally attractive place for birds and a number of cape district species were common. Among these were *Chaemepelia passerina pallescens, Melospiza melodia rivularis, Richmondena cardinalis ignea, Pipilo fuscus albigula,* and *Geothlypis beldingi goldmani.*

From October 10 to 16 I remained with one camp man at San Ignacio, while Goldman made a side trip to the Vizcaino Desert in search of antelope. From San Ignacio he took a westerly course about 25 miles to San Angel, a deserted ranch in the shallow Arroyo de San Angel on the eastern side of the desert, where holes in the arroyo give an abundance of good water. (See Pl. 11, Fig. 2.) Numerous date palms and natural forage plants were growing at this place, which, surrounded by shifting sand devoid of vegetation, forms a typical little oasis. Fifty miles to the westward across the desert he found the first water in that direction in the Tinaja de Santa Clara. (See Pl. 24, Fig. 2.) This is a fine tank of good water well hidden by the rocky walls of a small canyon on the western side of the Santa Clara Mountains. Some years ago, during the placer mining in the mountains to the northward, this tank was often visited but is now rarely seen by man. Goldman found antelope extremely scarce on this desert, where they were formerly numerous, but shot a mule deer far out on the flat open plain.

We left San Ignacio October 18 and ascended the very rocky course of the San Ignacio Arroyo easterly about 21 miles to La Cueva, a small unoccupied cattle ranch at an altitude of about 750 feet, backed by a huge shelter cave in the rough lava of the northern wall of the canyon in which we camped. On the opposite side of the canyon is a fine rock tank of good water, and water comes to the surface at a few places in the creek bed. A couple of miles above San Ignacio the valley narrows to a low-walled canyon with an extremely rocky bed, bordered on both sides by the gently sloping, rolling plateaus covered with loose stones. Large groves of palo blanco were scattered along the bottom of the canyon and a fine growth of large cactuses, tree yuccas, and copals covered the bordering hills. It was cloudy all day with light showers in the afternoon and at night.

October 19 the trail continued 5 miles easterly up the sloping mesa to the west base of the Santa Lucia Mountains, on the foot of which is a small cattle ranch known as the Rancho de Santa Lucia. Beyond this the slope became steeper, and the mesa led rapidly into the heart of the rugged Santa Lucia Mountains, which extend in a northerly and southerly direction. This is a narrow, sharp-ridged range, apparently almost wholly made up of beds of black lava, many of which rest in an almost original form. In the midst of the ragged peaks our trail forked, and we turned northerly on the one to the left. This led us to a small ranch in the bottom of a canyon, where we learned that we had chosen the longer trail to Santa Rosalia by way of Cerro Verde instead of the more direct one to the right which leads by the mining camp of Santa Agueda. From the ranch the trail led up a long, narrow, and extremely rough and rocky canyon to a knife-blade divide at an altitude of 2,000 feet, from which we had a fine view across the country we had traversed and ahead over lower country to the gulf. Descending the abrupt eastern slope to the bottom of a canyon at an altitude of about 800 feet, we camped about 20 miles from Las Cuevas under the shelter of some huge rocks just as it began to rain heavily.

October 20 the trail led easterly across a rolling mesa formed of deep beds of coarse rubble conglomerate traversed by deep, narrow and sharply cut canyons leading from the Santa Lucia Mountains to the gulf. After passing through about 15 miles of this country the trail entered a narrow canyon, along which for 3 miles were tramways and other signs of mining. At the mouth of the canyon, on the shore of the gulf, we came to Santa Rosalia, the largest and most prosperous town in Lower California. Santa Rosalia then had a population of about 7,000

[1] Another flood is reported to have swept down the valley in the fall of 1911, washing away houses and drowning more than 20 people.

people and is one of the larger copper mining camps of the world. It was the property of a French company which owns 1,000,000 acres of the surrounding country. By the terms of their concession the company exercises strict control over the town and adjacent country, the part taken in the government by the few local Mexican officials being much subordinated to the rule of the company. At the time of our visit there was regular steamer connection between Santa Rosalia and Guaymas, on the opposite side of the gulf, as well as with San Francisco. The mining company was building a breakwater of molten slag from their furnaces by means of which a safe harbor for the ships calling here will be provided; now they lie in the open roadstead, exposed to every storm. At this place the horse which became exhausted on the trail near San Ignacio was traded for another one, which was able to complete the journey.

We left Santa Rosalia October 25 and followed a trail 10 miles southeasterly across the stony mesas and intersecting canyons bordering the shore of the gulf, the mesas having an altitude of 100 feet or more and ending precipitously at the shore. The mesa country ended abruptly on the south and we descended to an open coast plain near the little fishing village of San Lucas, on the shore of a salt lagoon at the head of a small bay. The first mangroves seen during the journey were growing in this lagoon. They were 4 or 5 feet high and apparently the northern representatives of the species on the east coast of the peninsula. Following the shore of the bay southeasterly for about 6 miles we reached another small group of houses called San Bruno. The plain all about this bay appears to be underlaid at a small depth with fresh water. At San Bruno there was a little cultivated land including a small vineyard and olive orchard planted by an English company about eight years ago. These plantings were unsuccessful and were being abandoned at the time of our visit. A number of little patches of sugar cane and other crops were irrigated by means of shallow wells, from which the water was raised by long sweeps. The Anglo-Mexican Colonization Co. once had a colonizing concession here which was long ago abandoned. We remained one day at San Bruno to learn what birds and mammals occur there but found it an unproductive spot and on October 27 continued the journey.

From San Bruno the trail led southerly 8 miles inland across the coast plain to a water hole at the abandoned ranch of San Marcos, a few miles from the gulf. Seven miles beyond this place we came to a shallow well at another deserted ranch called Las Delicias, where we camped. The coastal plain here, as well as the top of the mesa along the coast near Santa Rosalia, is extremely arid but with a plentiful growth of desert shrubs which, with the exception of *Covillea*, were mainly leafless. Near Las Delicias we passed a belt of green a few hundred yards wide, like a broad ribbon across the brown plain, showing where a heavy shower had passed over the country some weeks before and wet the ground sufficiently to bring up the grass and other herbage. Several miles westerly from our route the gently sloping coast plain ends abruptly at the east base of the precipitous Santa Lucia Mountains.

October 28 the trail continued southerly for 10 miles across the coast plain, which was heavily overgrown with giant cactuses, and then southeasterly 5 miles through a range of low hills, 300 to 500 feet high, to the town of Mulege. This place is situated between low hills in the valley, a few hundred yards wide, of the Arroyo del Potrero, and at the head of a narrow lagoon extending more than a mile inland from Concepcion Bay. In 1705 a mission was established there and the town is now one of the most beautiful places in the peninsula, and at this time had about 750 inhabitants. Some large springs in the creek bed, just above the town, yield water for irrigation, and the place is embowered among groves of date palms, bananas, oranges, lemons, pomegranates, and fig trees, with fields of sugar cane and other crops interspersed. The old mission church stands on a hill by the town overlooking the valley, and on the long peninsula forming the eastern side of Concepcion Bay rises a barren rugged range of low mountains.

As at San Ignacio at this season the date palms and other fruit here attract many gray foxes (*Urocyon*), bassarisks (*Bassariscus*), striped skunks, and raccoons, which live in the shelter of the rocky walls of the valley by day and search the orchards for fallen fruit by night. We caught three gray foxes in the small palm grove at the upper end of Mulege the night we

camped there. These were caught soon after dark and attracting our attention by husky barks and yelps were taken from the trap by the light of a candle.

We traveled October 29 about 6 miles southwesterly, up the broad bottom of the Arroyo del Potrero to Poso San Rafael, a small cattle ranch on the eastern side of the arroyo with a shallow well in the dry creek bottom. The most vigorous growth of mesquites we saw in Lower California occurs along the sides of the arroyo near this ranch, many of them being 30 or 40 feet high, thus indicating abundant permanent water at a moderate depth.

October 30 the trail led southerly up the valley bottom, which gradually narrowed to a wide canyon with a broad dry wash, paved with water-worn bowlders, winding down its course; the size and abundance of the bowlders gave evidence of occasional heavy floods. About 10 miles from Poso San Rafael the valley narrows for a short distance to a low box canyon, and to the right rises a flat-topped mountain called the Mesa de Zacatecas, where numerous mountain sheep are reported to occur. The trail forks at this point, and the branch to the right leads about 2 miles to La Trinidad ranch near the base of the mesa. Continuing on the main trail 5 miles farther up the rocky and narrowing canyon we came to the ruins of El Potrero, an abandoned cattle ranch, where we camped. El Potrero is located at an altitude of 600 feet on a rocky mesa 6 or 7 miles in diameter with mountains on three sides, especially the southern side, which is limited by the precipitous walls of a high mountain ridge, plainly visible from Mulege, which bars the way like a wall in that direction. The Arroyo del Potrero heads at the base of this mountain wall, and the bottom of its narrow canyon through the mesa, immediately above the old ranch, contained numerous tanks and potholes of good water with a trickling stream here and there.

We left El Potrero October 31 and followed the trail southwesterly about 3 miles across the mesa to the base of an abruptly rising mountain slope, which it ascends in a series of sharp zigzags and along narrow ledges for about a mile to a pass on a sharp ridge at an altitude of about 2,400 feet. On both sides of this pass narrow mountain ridges forming the peninsular divide rise 1,200 feet or more higher and extend to the northwest and southeast. The mountain is so narrow at the pass that when the summit is reached the trail descends immediately on the other side into the narrow, cliff-bordered, and extremely rocky canyon forming the head of the Arroyo de San Jose, in which for half a mile or more the slope is even more abrupt than on the side we ascended. This narrow divide forms the watershed of the peninsula, the drainage on the north being to the gulf and that on the south to the Pacific. Six miles below the summit we passed a number of stone-walled inclosures and ruins of houses marking the long-abandoned Guajademi ranch. Four miles below this were the ruins of El Zapote, another abandoned ranch; 3 miles below, another one called Los Candelitos; and 3 miles still farther down was Agua Grande, a deserted ranch, with a tank of water in the bottom of the canyon. At all of the places named there were water holes in the rocks and traces of former occupancy, but all had long been abandoned. A few cattle were still ranging about Agua Grande, and the water was extremely filthy, but none of the party knew the country ahead and, owing to the condition of our stock, we could not risk a dry camp, so we stopped there and made the best of it. The next morning, only 2 miles below this camp, we found a large tank full of good clear water.

A vigorous and abundant growth of giant cactuses and other desert plants occupied all the lower slopes of the canyon, and wild fig trees were growing in several places where water was close to the surface. A number of pyrrhuloxias and ground doves were seen near the water holes, and at Agua Grande the call notes of the pigmy owl (*Glaucidium hoskinsi*) were heard on all sides as we were breaking camp, the only time we heard this species during the journey. This locality is worth some careful work, but feed was so scanty and our stock in such worn condition we considered it imprudent to remain there even for a day.

About 9 miles down the canyon from Agua Grande we passed a little ranch called San Joselito, occupied by a single family. Four miles below this we came to San Jose, a larger ranch, with some date palms and a small field of sugar cane. Five miles below San Jose was Rancho Hondo, which was occupied, and just below it a crossing of the canyon known as Paso Colorado, where

we camped under a large mesquite tree. Water rises in the canyon just above Rancho Hondo and a small stream bordered by rushes and willows flows by Paso Colorado. During the afternoon clouds gathered, and it began to rain. From Agua Grande to Rancho Hondo the canyon varies from one-fourth of a mile to a mile broad, but widens below the last-named point and the walls become much lower, descending southward toward the Pacific coast.

November 2 we continued about 3 miles down the canyon to the small village of Purisima Vieja, where the trail turns to the left and climbs the wall out of San Jose Canyon and leads across the broad plateau thickly covered with angular fragments of lava. From the top of the divide above Guajademi down to Purisima Vieja the trail follows the bottom of San Jose Canyon.

All the mountains in this district are of volcanic origin, and the Pacific slope forms a continuation of the lava-covered plateau we traversed near San Ignacio. This plateau is cut in all directions by deep ragged box canyons like the upper part of the San Jose Canyon near Guajademi. The rocky walls of San Jose Canyon rise almost vertically in a series of steplike mesas, the cliffs in some places having a talus slope, but often rising as clear vertical walls. This entire section is of black lava, overlying basal beds of sandstone and hard conglomerate, which unite to give a gloomy and savage aspect to the rugged wildness of the scenery. This volcanic plateau formation continues throughout the length of the canyon, but the walls become increasingly lower and the bottom broadens from above Paso Colorado to Purisima Vieja and below. Purisima Vieja consists of a small group of adobe houses surrounded by a few date palms and small fields, mainly planted with sugar cane and irrigated from springs, which rise in the canyon bottom.

At the point where our trail ascended the southerly wall of the canyon the plateau has an altitude of about 900 feet and slopes southwesterly toward the coast plain. After traveling in a steady rain 10 miles from Purisima Vieja southerly and then southeasterly over the undulating and broken lava beds, varying in altitude from 1,000 to 1,300 feet above the sea, we came to the top of an escarpment nearly 1,000 feet high overlooking the picturesque valley and town of La Purisima, the seat of one of the old missions. When we arrived at La Purisima the storm, continuing all day, had increased to a cold, driving rain and, owing to the small size and crowded condition of the houses, we found it difficult to secure a place for ourselves and outfit. Nearly every roof in town was leaking abundantly, and the room we finally secured in which we crowded with all our saddles and the loads of four pack mules, gave but partial shelter. The main group of houses, many of them whitewashed, was located near the old mission at an altitude of about 300 feet in the flat-bottomed valley nearly opposite the point where our trail approached the edge of the mesa, but other small houses were scattered among fields for 8 or 10 miles up and down the bottom. At the time of our visit this valley had from 400 to 500 inhabitants.

La Purisima Valley varies from one-fourth of a mile to a mile in width and is bordered by precipitous walls, 500 to 1,000 feet high, with a lava cap on the mesas extending away on both sides. The rocky walls are eroded into many curious forms, which add much to the picturesque interest of the surroundings. The largest stream in central Lower California rises from springs near the head of this valley and flows down its course, irrigating many small fields in which are grown numerous date palms, orange, and other fruit trees, mission grapes, bananas, sugar cane, and corn. One of the main industries is that of making raisins from mission grapes, which are packed on donkeys to San Gregorio Landing, on the Pacific coast just south of the mouth of Purisima Canyon, and shipped in small sailing vessels to the mainland of Mexico. A few miles below town the canyon opens out on a broad coastal plain where there is said to be much fertile land. An American company prospecting for oil some years ago is reported to have sunk a well in the lower end of the canyon, and the natives informed me that it had been flowing good water ever since. This indicates the possibility of getting artesian water for irrigation on some of the coastal plains in this region.

The rainstorm continued two days and ended in a dense fog which filled the valley. The morning of November 4 the fog cleared away and after partly drying our outfit we continued our journey. The trail led from near the lower end of the town up about 1,000 feet to the top

of the abrupt south wall of the canyon, and thence southeasterly across the rolling and broken plateau. About 6 miles from La Purisima we came to a deep box canyon, in the bottom of which San Vicente Ranch is located, the house standing in the midst of a few date palm, lime, and zapote trees, near small patches of corn and sugar cane. A small stream of water rises in the bottom of the canyon and flows enough to irrigate this small oasis, which supports a single family in the midst of a gloomy waste of broken lava. From San Vicente the trail led down the canyon and then up a tributary gorge on the left to the top of the plateau, where we entered a great series of lava beds descending from a conical crater a few hundred feet higher than the general level. Here for miles on all sides lie beds of bare, shattered lava containing occasional small patches of soil on which were growing various species of desert bushes with a few giant and other cactuses. With some difficulty we found a small patch of ground partly free from stones for our beds and camped at an altitude of about 1,300 feet near the base of the old crater peak. During the night a solitary huge black cloud swept over the otherwise brilliantly clear sky and gave us a hard shower.

November 5 the trail continued about 18 miles southeasterly through the broken plateau country among scattered volcanic crater cones which rise from about 300 to 1,000 feet above the general level. Each cone is the center of a series of lava beds which spread over the surrounding plain. The surface of the lava beds is covered with angular masses of shattered lava through which the animals had to pick their way with much care. Canyons of varying depths gash the surface of this great volcanic plain, which gradually rises to its greatest elevation in this district about the base of La Giganta, near Comondu. The lava beds of the surface are underlaid by stratified beds of volcanic ashes and similar material, usually consolidated into soft rock. The great expanse of broken lava lying between Guajademi and Comondu gives a wild and savage aspect to the district. In places between La Purisima and Comondu the trail was boggy from the recent rains and added to the difficulties of the road, for the general surface was such a continuous bed of lava that we were confined to a narrow track winding among the shattered rocks. About noon we crossed a broad rounded divide about 2,000 feet above sea level and descended the farther slope to an altitude of 1,500 feet, where we came abruptly to the edge of the canyon wall immediately opposite the village of Comondu. This is a scattered settlement of about 1,000 people located at an altitude of about 700 feet along the flat bottom of a canyon varying from 200 to 800 yards in width, and with walls from 500 to 800 feet high. A stream rising in large springs near the upper end flows about 8 miles down the canyon and irrigates a continuous succession of small fields. Date palms were scattered irregularly along the stream in a thin line through the small vineyards and fields of corn, sugar cane, and other crops, and other palms were grouped with the orange, fig, and pomegranate trees about the houses. The view up and down the canyon from the top of either wall is one of the most beautiful in the peninsula. (See Pl. 13, Fig. 2.)

For several miles along the plateau before we came to Comondu the trail followed an old wagon road over slopes on which there was a scattered growth of large agaves. Here and there the road branched and led across the slopes to one side or the other. At Comondu we learned that these roads were made some years ago by an American company which built wagon roads from the landing on the coast to Comondu and over the adjacent hills, brought machinery up from the coast, and put up buildings with the purpose of extracting the fiber from the agaves growing there. The enterprise was foredoomed to failure and the old roads and one or two abandoned houses in the canyon near Comondu are all that remain of it.

Bryant, Brandegee, and others who have visited Comondu speak of the kindly treatment received from the people there, and we met with the same hospitable reception. The visit of Bryant and Brandegee was still remembered, and the mayor of the town in 1905 was the man who outfitted them with saddle and pack animals for their overland trip to San Quintin in 1889. Comondu has an almost purely tropical climate, although light frosts are not very uncommon in winter and at intervals are severe enough to kill the leaves on sugar cane. Malarial fever, called "morongo," is reported to occur here in summer, and elsewhere about irri-

FIG. 1.—Western border of Vizcaino Desert. Santa Clara Peak in background.

FIG. 2.—Comondu Valley. This is a broad canyon in the lava plateau, with a stream and fertile soil, making a [illegible] date palms and other tropical and subtropical fruits.

gated areas in Lower California as far north, at least, as Mulege, where a number of cases occurred in 1904. These fevers are reported to be rather severe and often fatal to old people.

After several days of productive work at this interesting locality, we resumed our way November 10, following the wagon road southwesterly down the canyon. A mile below town the walls close in and the canyon for about 12 miles is narrow and very crooked, the high basaltic cliffs forming many wild scenes. Then the canyon broadens and the walls descend gradually for 3 miles before they merge into the gently sloping coast plain, which is about 12 miles wide at this point. The lava cap to the mesa forming the south wall of the canyon below Comondu is largely columnar basalt, but the north wall is mainly of horizontal strata apparently very different in character. The water appears to have formed the canyon by following the line of contact between two distinct lava flows. Below the mouth of the canyon we turned to the right from the wash for a couple of miles to a small occupied cattle ranch called El Batequi, 19 miles from Comondu, where a shallow well furnishes the only available water on this part of the plain.

November 11 we crossed the broad sandy wash where Comondu Arroyo spreads over the plain, and taking a more southerly course for 10 miles over the slightly undulating surface came to a deserted ranch called Poso Grande, where there was good water in a shallow hole in the sandy bed of an arroyo. Two families of Mexicans with nine small children were temporarily camping here in small brush huts. An old cornfield close by showed that crops are sometimes grown here by subirrigation. Poso Grande is 3 miles inland from San Jorgé, the head of boat navigation in the long narrow lagoon leading north from Magdalena Bay. Dried fruits, hides, and other products from Comondu are shipped from there by small boats to the bay, and other articles are brought in. From our camp at Poso Grande and from far up and down this coastal plain the high solitary volcanic peak of La Giganta, located on the volcanic plateau between Comondu and Loreto, stands up boldly as a striking landmark.

November 12 we remained at Poso Grande to do some work on this part of the coast plain. Several showers had fallen during the last two nights, but in the afternoon a sea breeze came in and the sky was cleared of threatening clouds for the first time since we left Mulege about two weeks before. It had rained at intervals throughout this time. These winter storms in the southern half of the peninsula are called "equipatos," and sometimes heavy rains continue for two weeks and render the country so boggy that travel is impossible. November 13 we traveled 14 miles southerly parallel to the coast over the same slightly undulating sandy plain and made a dry camp in a heavy forest of gigantic cactuses and other desert plants. The gentle undulations on this plain appear to be due to the formation of broad low swells by the drifting sand from the coast. About 10 miles south of Poso Grande we passed another abandoned ranch called Poso Medano Blanco.

November 14 we continued southerly over the same coast plain and about 8 miles from camp passed the deserted ranch of Santo Domingo on the bank of a deep dry wash where some well-made adobe houses were going to ruin. Here a water hole in the sandy wash enabled us to water our stock. Just south of Santo Domingo, on a large flat extending along the course of the dry wash, we passed through a fine large growth of mesquite trees, indicating permanent water at moderate depth. There is much fine farming land here and all along this coast plain, which needs only water to become very productive.

In the afternoon we crossed a broad belt of country in which there was a good fresh growth of grasses and other herbaceous vegetation, 4 to 6 inches high, most of which was ripening its seeds. Some ranchmen living in this section we met told us that a heavy rain fell here on August 7 which resulted in this growth. Just before nightfall we suddenly passed the border of this belt of green into the brown arid desert again and in order to give our stock the advantage of the fine pasturage were obliged to turn back and reenter the green belt to camp.

November 15 we traveled southerly along the same coastal plain, parallel to the shore but some miles inland, and 20 miles from camp reached Matancita, or Soledad, ranch. This is the headquarters cattle ranch of the Chartered Co. of Lower California, an American corporation which holds a concession covering a belt about 16 miles wide all along this coast from a little

south of Magdalena Bay north to beyond Scammon Lagoon. We were hospitably welcomed by the local manager of the company, Mr. W. J. Heney. Formerly this ranch was headquarters for the orchilla-gathering business spoken of below. Matancita ranch is 10 miles inland from the shore of the coast lagoon which gives boat communication with Magdalena Bay. The ranch has some good adobe houses and a steam pump for raising water to irrigate a small vineyard, orchard, and garden. A shallow well in the deep channel of the large dry arroyo which passes the ranch supplies an abundance of water for pumping and indicates the possibilities of the numerous similar arroyos we crossed along the coast plain to the north. The discovery of oil in Lower California, which would supply cheap fuel for pumping water, would undoubtedly result in the reclamation of much productive land along the west coast of the peninsula.

The coast belt owned by the Chartered Co. contains practically all the land of the peninsula on which orchilla grows and was formerly gathered. The orchilla (*Roccella*) is a lichen resembling Spanish moss in appearance which grows abundantly on the branches of *Fouquieria peninsularis* and other shrubs and low trees along this part of the western coastal plain and was formerly used extensively for dyeing purposes. The inventions of chemically produced dyes destroyed this industry, in which the original company (Flores, Hale & Co.) made large profits. The company in control at the time of our visit had cattle ranging from Matancita ranch south to opposite Magdalena Bay, from which visiting warships in the bay and other vessels were supplied with fresh beef.

From November 16 to 19 we remained at Matancita, working the surrounding plain. A narrow belt immediately along shore has only small herbage and stunted bushes, resembling that in the vicinity of San Quintin, but back of this the coast plain is covered with a vigorous growth of giant and several other species of cactuses, *Fouquieria peninsularis*, and many other desert shrubs and small trees, sometimes forming a dense jungle.

November 20 we left our pack outfit at the ranch and accompanied Mr. Heney in his buckboard 10 miles westerly to Soledad Landing, on the lagoon leading to Magdalena Bay, where we boarded the company's sloop *Catarina*. This lagoon is a riverlike channel from one-fourth to more than 2 miles wide, which extends along shore about 60 miles north from Magdalena Bay. It is bordered on both sides by a belt of mangroves and is separated from the sea by a low strip of sand which forms the northern end of Magdalena Island. The afternoon of November 22 we arrived at the settlement of Magdalena Bay, 50 miles south of Soledad Landing. (See frontispiece.) This small village, on the eastern or inland side of the mountains, near the south end of Magdalena Island, faces the bay 2 or 3 miles northwest from its entrance. It consists mainly of a large, well-made two-story residence, with stores and warehouses of the company and a number of smaller houses occupied by the employees and by Mexican customs officials. During the continuance of the orchilla industry this place had a much larger population. At the time of our visit the main export was a monthly shipment of sea turtles to San Francisco on the Pacific Coast Steamship Co.'s boat, which called here regularly. The south end of Magdalena Island forms a narrow rocky ridge a few miles long rising abruptly from the sea to over 1,500 feet at its highest point and presenting a bold and rocky head at the entrance of the bay.

November 27 Mr. Heney took us in his sloop across the bay to Margarita Island. We landed on the shore of Almejas Bay, on the east side of the island, at the site of an old canning establishment where an unsuccessful attempt was once made to can sea turtle for export. A small frame house on the beach is all that remains to mark the spot. Immediately back of the landing the shore is bordered with some small salt lagoons full of mangroves, in which a considerable colony of man-o-war birds have their nests. The young of the year, though fully grown and on the wing, were still spending much time about the nests and hundreds of young and adults roosted there at night. This place is on the easterly side of the low flat area which crosses the middle of Santa Margarita, separating the mountainous northern and southern ends of the island. The western side of this pass forms a low flat, just inside a belt of high sand dunes bordering the shore, where fresh water exists within a few feet of the surface. Traces of old fields and the ruins of a ranch house were evidences that an effort had been made to cultivate this flat. Several small groups of date palms growing here were being buried by the advancing

FIG. 1.—Open roadstead steamer-landing on beach at San Jose del Cabo, January, 1906. Crates on beach contain brown sugar in small cakes for shipment to other points in Lower California and to Mazatlan.

a central point, and while the parent stem dies the continual growth at the front end causes the separate stems actually to travel away from the starting point.

FIG. 1.—Servatillo cattle ranch on plain east of Magdalena Bay. Beef for ships in Magdalena Bay is gathered about this and neighboring ranches.

FIG. 2.—Water front at La Paz, January, 1906. This is the capital of the southern district of Lower California. It was the point first occupied by the Spaniards and is the best town in the peninsula.

sand dunes. We remained on Santa Margarita until December 1, when we returned to Magdalena Island. Our accumulated specimens were shipped on the steamer for San Francisco, and December 5 we started with Mr. Heney on our return to Matancita ranch, but calms delayed our arrival until the 8th.

December 9 we resumed our journey on horseback and traveled about 16 miles southeasterly across the slightly rolling coastal plain to a dry camp in the cactus forest. The sky was heavily clouded and we put up our tent between two giant cactuses, so we were sheltered from the rain that began during the latter part of the night.

December 10 we broke camp in the rain and continued our journey in a more southerly course. A cold southeast wind drove the rain with such force that we were quickly wet through and thoroughly chilled, so we rejoiced to reach shelter at Servatillo ranch, 7 miles from camp. (See Pl. 15, Fig. 1.) This is one of the Chartered Co.'s cattle ranches and consists of two small adobe houses and a corral by a well on the plain. The altitude here, as well as all along our course from near Poso Grande, is about 50 feet above the sea. It rained heavily all day and most of the following night but cleared on the morning of December 11. We then traveled about 15 miles southeasterly over the plain to La Cruz, another small cattle ranch belonging to the company and occupied by a Mexican family.

The rain of the last 36 hours had flooded the coastal plain so that all depressions, including the trail, were full of water, and torrential streams ran in all the ordinarily dry channels. La Cruz ranch is located on the plain a few miles immediately inland from Magdalena Bay, on what is known as the Llano de Yrais. In 1871 an extensive but unsuccessful effort was made by an American company to locate an agricultural colony on this plain. The part of the coast plain we traversed from our camp north of Servatillo ranch to La Cruz is nearly flat, with a gentle slope toward the coast lagoon and Magdalena Bay. A belt of sand dunes along the east shore of the bay was in plain view along this part of the route, while far to the east the broad plain is limited by a high plateau and range of mountains paralleling the gulf coast and occupying the eastern third of the peninsula.

We remained at La Cruz December 12 and tried to secure specimens of a small fox reported to occur in open parts of the plain. December 13 we continued in a southeasterly course over the plain. About 3 miles after leaving La Cruz we came out of the cactus forest into an irregularly shaped open prairie, about 10 miles long in an easterly and westerly direction and from 3 to 4 miles broad, with its western end near the sand dunes on the east shore of Magdalena Bay. This is the Llano de Yrais proper, though the name has been used to cover the adjacent plain as well. This open prairie appears to be a kind of shallow, nearly flat sink and was largely under water at the time we crossed it. The preceding day Goldman had set several fox traps near burrows on the higher parts of this plain, and as we passed we took them up and secured three foxes. These proved to represent a previously unknown form of the graceful, big-eared desert fox. Formerly many antelope lived on these plains, but they are now extinct south of the Vizcaino Desert. Many low places along this part of the trail were covered with broad sheets of shallow water, in which giant cactuses and other desert plants were standing, thus giving a grotesque appearance to the scenery. The country gradually became less muddy and more sandy. Late in the afternoon we entered more rising and slightly rolling country, over which small fragments of volcanic stone were scattered. About 26 miles from La Cruz we came to the first definite dry wash or creek bed since leaving Soledad. The trail crosses this wash at a point where a small clear stream of excellent water rises and flows a short distance down the bottom. Here, at an altitude of about 100 feet, is located El Sauz, a small cattle ranch, where we camped. The high bank of the wash, as well as exposed sections of some low mesas passed on the trail, show that this part of the country is underlaid near the surface by a thin blanket of volcanic tuff (tepetate). On the Llano de Yrais we passed beds of an extraordinary creeping cactus (*Lemaireocereus eruca*) which we saw nowhere else. (See Pl. 14.)

December 14 we continued in a southeasterly course about 35 miles to an old cattle ranch called Agua Colorado, on the banks of the Arroyo Colorado or Arroyo de la Junta, in which there was a small stream. We camped at an altitude of about 75 feet in an abandoned hut

at the foot of a bluff on the northern side of the creek. Another small house on the opposite bank was occupied by a Mexican family and some cowboys. Our route that day led alternately across nearly level, and gently undulating, gravelly and stony mesas separated by broad washes or little drainage valleys with abrupt banks 40 or 50 feet high.

December 15 the trail led about 10 miles southeasterly across low, rolling hills to the little village of San Hilario on top of the high northern bank of a small stream of the same name. This arroyo irrigates some small vineyards, small fields of sugar cane, and other crops. A few date palm trees and some fan palms, perhaps of two species, were also noticed. A little wine is made here. Among the hills 3 miles beyond San Hilario we came to the junction of our trail with the one leading from the old mission of San Luis to La Paz. We had been approaching the basal slopes of the main plateau and mountains of the east side of the peninsula for the last two days and were now in distinctly rolling country. Three miles southeasterly from the junction of the trails was an abandoned hut on top of a bluff overlooking the deep Arroyo Guadalupe, in which there was a small stream flowing over a rocky bed. Beyond this arroyo the country changes and becomes much rougher and is broken into series of low, narrow hills and ridges. Back of these toward the mountains to the east were the sharply rising fronts of low, scattered mesas, the formation of which was similar to that of the hills and ridges we were crossing and indicated that both were made by the erosion of a great plateau sloping down from the high range to the eastward. The trail continued in a winding course about 12 miles from Guadalupe through this broken country to Cerro Colorado. This latter is a buffy-colored conical hill standing immediately in front of and evidently weathered from the lower border of the high interior mesa. We made a dry camp at an altitude of about 800 feet just above the base of this hill.

The coastal plain we traversed all the way from below Comondu to the vicinity of Agua Colorado, except the belt close along the seacoast and the restricted Llano de Yrais, was covered with an irregular but heavy growth of desert vegetation, among which hosts of giant cactuses and several other cactuses, large and small, *Fouquieria peninsularis*, and many other desert and arid tropical species form a low scattered forest.

December 16 the trail led southeasterly from Cerro Colorado directly up a steep escarpment to an altitude of about 1,200 feet on the top of a broad rolling plateau covered with broken lava. From the point where we first reached the top the plateau rose gradually to an altitude of 1,400 feet, which was the highest point we crossed between Cerro Colorado and the gulf. Its surface is the roughest and most broken we had seen on any of the lava plains crossed to this point. This is due in part to its surface being cut by deep, ragged box canyons and their numerous small tributaries, some draining to the Pacific and others to the gulf. The plateau rises steadily toward the gulf on the southeast and breaks off in abrupt escarpments, forming cliffs fronting La Paz Bay, and from the crest slopes gradually westerly and southerly to the broad coast plain of the Pacific. For 20 miles we traveled the roughest trail we encountered during the entire expedition, to the crest of the abrupt escarpment on the gulf side, at the head of a large box canyon known as the Cajon de los Reyes. Here the trail led down a steep declivity, called El Salto de los Reyes, to the bottom of the canyon. Thence we followed its winding course for 10 miles, between high and picturesquely sculptured walls, to its mouth near the shore of La Paz Bay. Throughout its course this canyon cuts through an extension of the high plateau we traversed in the morning. The plateau, which is of sandstone overlaid by lava beds, ends in a series of high cliffs fronting all the westerly and northerly shores of La Paz Bay and separated from it by a sandy coast plain 2 or 3 miles broad. A vigorous growth of giant cactuses, mesquites, and other desert species covers the sandy plain over which we traveled about 5 miles from the mouth of the canyon to Rodriguez, a little group of huts forming a milk ranch on the shore of La Paz Bay, where we camped.

December 17 we continued in a southeasterly and then northeasterly course for about 22 miles to the town of La Paz, on the eastern side of the bay. (See Pl. 15, Fig. 2.) Our route followed the shore of the large inner bay or estero, a shallow lagoon which has a narrow outlet into the main bay close to La Paz. We were surprised to see so few waders and other water-

fowl along the muddy flats bordering the lagoon. La Paz is the capital of the southern district of Lower California and next to the largest town in the peninsula, being second only to Santa Rosalia, and contained about 5,000 people. It is a beautiful place close to the shore at the head of the bay and embowered in coconut and date palms, orange, lemon, pomegranate, avocado, banana, and other trees and shrubs. The country about the town is an arid desert with mesquites near the bay and creosote bushes and other desert species farther back. The open plain slopes gently back from the bay and the sharp peaks of the Cacachilas, rising boldly a few miles to the southeast, are the nearest mountains. To the southwest the low plain forms a broad pass between the inner bay and the Pacific side of the peninsula, and thus separates the mountains and high plateaus of the north from the mountain groups to the south. In front of the town lies the broad sweep of La Paz Bay, bordered by cliffs along its northwestern shore and with Espiritu Santo and San Jose Islands lying just outside in the gulf.

La Paz is the headquarters of the pearl-fishing industry of this region extending from the Gulf of California south to the coast of Guerrero. The business is in the hands of two or three companies holding concessions from the Federal Government. Mr. James Viosca informed me in a letter dated May 4, 1906, that at that period these fisheries were yielding each year about $250,000 in pearls and $120,000 in mother-of-pearl shell.

We made another shipment of specimens from La Paz and on December 23 continued our journey toward Cape San Lucas. Our route lay nearly due south along a good wagon road over a gently rolling and slightly rising plain. In the afternoon we camped at San Pedro, a little cluster of ranch houses about 18 miles from La Paz at an altitude of about 700 feet. Some fields are dryfarmed here, but as they are dependent on the irregular rainfall for a crop the results are uncertain.

December 24 we traveled southerly along the wagon road for about 17 miles to Tres Pachitas a small ranch on the sloping plain at about the same altitude as San Pedro. About 5 miles out from San Pedro the road forked, a branch turning to the left and leading to the mining camp of Triunfo. Our route lay over the same rolling plain we had traversed all the way from La Paz, but we were gradually approaching the outlying foothills of the northern end of the Victoria or Laguna Mountains. The growth of desert vegetation was very large and abundant along the last part of this road, and a number of tropical shrubs, including an *Erythrina*, were seen for the first time. The luxuriance of the vegetation near Tres Pachitas indicates a much greater rainfall than nearer La Paz, which is evidently due to the proximity to the high northern end of the Sierra de la Laguna, where summer rains are comparatively regular.

December 25 we journeyed about 14 miles southerly along the road from Tres Pachitas and reached another small ranch called Valle Flojo, located about 3 miles from the coast beside a large dry wash at the bottom of a broad canyon about 100 feet deep. At Tres Pachitas the road approaches the north end of the Sierra de la Laguna, which forms the northern section of the Victoria Mountains, and after leaving that place we found the country much more rolling owing to the series of long rounded ridges which lead northerly from the base of the mountains and drain on the southern end of the great Magdalena Plain. The road gradually swung around the north and west base of the Sierra de la Laguna, which rises precipitously several thousand feet on this front to Valle Flojo. Shortly before we reached this ranch we passed two low flat-topped hills which form part of a series extending from the road northwesterly for some miles parallel to the Pacific coast.

The abundant growth of small vegetation and the heavy foliage on shrubs and trees all along the route from within a few miles of La Paz were evidence of abundant rains during the past season. Near La Paz conditions are always much more arid than elsewhere along this route and in consequence the vegetation in that vicinity is smaller and more scanty, but as the mountains are gradually approached and a few hundred feet in altitude gained, the vegetation becomes much larger and more abundant. Huge giant and other large cactuses were the most common and striking elements in this junglelike forest, which varies from 15 to 40 feet high.

December 26 we crossed a continuation of the broken country for about 12 miles southerly from Valle Flojo to the village of Todos Santos. This is a pretty place, consisting of 30 or 40

houses at an altitude of about 100 feet on a low bare ridge overlooking a narrow valley which is the lower end of a broad canyon leading from the west base of the Sierra de la Laguna. Below the road the valley was bright green with waving fields of sugar cane, and beyond, 2 or 3 miles away, lay the blue waters of the Pacific. A number of tall fan palms about the houses and cane fields and mango trees along the irrigating ditches added to the attractiveness of the place. Water for irrigation comes from some large springs in the bottom of the valley. Formerly the springs were located high up the valley above the road from La Paz, but some years ago they suddenly became dry and then burst out lower down, where they are at present, thus necessitating the abandonment of all fields above the road.

For about 10 miles beyond Todos Santos the road continued southerly over low rolling ridges, which lead down from the high mountains on the east, to Pescadero, a small group of huts a couple of miles from the sea. These huts are on two low hills overlooking some small sugarcane fields in the flat between the houses and the sea. Immediately north of Todos Santos the outlying foothills of the Sierra de la Laguna reach the Pacific coast and, as southward toward Cape San Lucas where the descending foothill slopes of the Victoria Mountains reach the coast, they usually end in cliffs along the shore.

December 27, 12 miles south of Pescadero, we came to the San Jacinto ranch, consisting of a few huts located within half a mile of the sea beside a broad sandy wash in a baylike coastal valley. The dry wash was bordered near the crossing by beautiful groups of tall fan palms, their presence giving evidence of water a short distance below the surface. Our route all day was generally parallel to the coast and within 2 or 3 miles of it, and several low ridges alternating with small coastal valleys extending from 2 to 4 miles inland were crossed. These coastal valleys are mainly flat, but are sometimes broken by low hills or ridges and crossed by sandy washes coming down from the west slope of the Victoria Mountains. In the afternoon the trail left one of the valleys and ascended the highest and most abrupt ridge we had yet seen along this part of the coast, bringing us to Cajoncito, a small cattle ranch located at an altitude of about 1,000 feet on a bench just below the summit of the hills, about 21 miles southerly from Pescadero.

All along the route from north of Todos Santos the westerly front of the Victoria Mountains, 8 to 12 miles inland, parallels the coast, and rises with abrupt and inaccessible slopes of bare rock to a ragged line of peaks from 3,000 to 6,000 feet above their basal foothills. These mountains and the foothills and ridges leading to the coast are mainly of pale gray granite resembling that in the high mountains of the northern half of the peninsula, but with their most abrupt slope facing the Pacific instead of the gulf.

December 28 the trail held in a generally southerly course all day, but was extremely crooked, swinging down to the coast and then far inland, winding among the roughest and most broken hill country we had seen since leaving La Paz. About 12 miles by trail from Cajoncito we turned inland from near the ocean and traveled about 8 miles southeasterly across foothill ridges to Saccaton, a small cattle ranch situated at an elevation of about 1,000 feet and about 5 miles from the sea. All along this part of the route the main foothill ridges descend to the Pacific, forming bold rocky points and bluffs with broad sandy dry washes in deep ragged canyons between them. The vegetation along the coast from Todos Santos to Saccaton is much like that farther back on the road to La Paz but is smaller and less abundant.

December 29 we crossed a high narrow ridge immediately south of Saccaton, on the far side of which the drainage flows toward the southern end of the peninsula. Descending this south slope we followed a series of dry washes down their winding courses through the hills and finally came out on a long, open sandy slope descending southward to the sea. This slope is bounded on the east and west by series of granite hills, giving it the form of a valley, down which broad sandy washes lead to the shore of Cape San Lucas Bay. The slope is covered with a vigorous growth of large and small cactuses, mesquites, and numerous desert and arid tropical plants. Early in the afternoon, about 15 miles from Saccaton, we reached the village of Cape San Lucas on the shore of the bay, the end of our long southward journey. (See Pl. 18, Fig. 1.) The bay is bounded on the southwest by a low granite ridge terminating in two de-

FIG. 1.—Jungle of Arid Tropical and Lower Sonoran vegetation on northern foothill slopes of the Sierra de la Laguna, between La Paz and Todos Santos.

FIG. 2.—Sugar-cane fields at Todos Santos. A beautiful little valley near the Pacific coast, irrigated from a small spring.

FIG. 1.—A small coastal plain at El Pescadero, south of Todos Santos, showing the trail leading south to Cape San Lucas. Victoria Mountains in the background.

FIG. 2.—View westward across San Jose Valley at Santa Anita ranch. The Sierra San Lazaro in the distance.

FIG. 1.—Cape San Lucas. The granite ridge forming the point of the cape lies on the west side of the small bay. The village of Cabo San Lucas is back of the sand dunes in the foreground.

FIG. 2.—San Jose del Cabo in 1906. This place had about 1,500 inhabitants. It lies a little back from the shore about 23 miles easterly from Cape San Lucas near the lower end of a fertile little valley.

tached granite knobs standing boldly out of the sea and forming Cape or Cabo San Lucas. The village of Cape San Lucas contains about a dozen families who occupy a small group of adobe houses on a flat just back of the broad sandy beach and only a few hundred yards easterly from the base of the cape. It was formerly a much more populous and prosperous place. At the time of our visit the inhabitants were making a livelihood mainly by gathering tan bark from small trees on the sloping plain back of the town and shipping it to San Francisco. A few date palms among the houses, the tropical jungle behind, and the blue sea in front unite to make this a most picturesque spot. We obtained the use of a vacant house and spent a few days securing specimens from a place of historic interest to American ornithologists through the work done here in 1859 by John Xantus.

January 4, 1906, we left San Lucas and followed a trail northeasterly along the coast, sometimes on the sandy beach but mainly a mile or two inland. The country was broken by numerous granite ridges, 100 to 500 feet high, extending to the sea from the low southern end of the Victoria Mountains, a few miles inland, and separated by deep, sandy, dry washes. About 23 miles from the cape we came to San Jose del Cabo, which is a well-built town of adobe houses and contained about 1,500 inhabitants. It is located on a low slope on the west side of the valley and about a mile above the mouth of the Rio San Jose, which reaches the sea here. (See Pl. 18, Fig. 2.) San Jose Valley, 1 or 2 miles wide, is very fertile, and by means of irrigation from the river good-sized fields of sugar cane and other crops are cultivated on the flat between the town and the coast. Some parts of the bottom bordering the river were overgrown with willows and other bushes. About the town were many orange, lemon, pomegranate, banana, and other fruit trees, and numerous tall and graceful fan palms were scattered about the fields. The permanent supply of water in the river and the fertile valley lands make this one of the largest and most prosperous agricultural places on the peninsula. Steamers from and to San Francisco and the mainland of Mexico stop here regularly twice a month, the landing place being on the open beach near the mouth of the river. We remained at San Jose several days to secure topotypes of birds and mammals in a locality where Xantus, Bryant, and other naturalists have worked. The night of our arrival (Jan. 4–5) was the coldest of the season, the temperature dropping close to the freezing point.

January 10 we traveled about 8 miles northerly up the west side of the valley to Santa Anita, a ranch where we were hospitably welcomed by the proprietor, F. Pazjk. (See Pl. 20, Fig. 1.) This place has been visited by various naturalists, including Dane Coolidge, Loye Miller, and J. E. McLellan, and is the type locality for several species of mammals. San Jose Valley is bounded on both sides by hills and mountains and varies from a mile in width near San Jose to several miles at Santa Anita. The west side of the valley is walled in by foothills of the high range of the Victoria Mountains, and west of Santa Anita the peak of San Lazaro, in this range, rises several thousand feet and forms a bold and striking landmark. To the east the valley is limited by the gentler slopes of the Sierra de la Trinidad.

Giant cactuses and other desert plants with a strong tropical mixture form a vigorous and abundant vegetation all along the bottom of the valley, while groups of tall fan palms at Santa Anita tower above everything else. (See Pl. 17, Fig. 2.) The top of a long mesa to the north between Santa Anita and Miraflores is more arid than the valley bottom, and many giant cactuses and ocotillo (*Fouquieria peninsularis*) give a resemblance to the vegetation of parts of southern Arizona. The slopes of all the mountains within sight are bare and rocky.

January 19, having completed our work at Santa Anita, we continued northerly on the west side of the valley. Our trail lay over a rolling and canyon-cut mesa from 50 to 150 feet above the river bottom, which had a dry and rocky bed through most of its course. About 12 miles north of Santa Anita the mesa becomes lower and the trail descends into the river bottom, where a small stream was flowing, and scattered individuals of a small but handsome live oak 20 to 40 feet high, with small narrow leaves, and drooping branches, made an attractive addition to the flora. Thence up the valley to Miraflores, about 18 miles north of Santa Anita, these oaks were rather common along the bottom. Miraflores is an attractive village of 30 or 40 houses at an altitude of about 400 feet on the west side of the San Jose River, just above its

junction with the Arroyo San Bernardo, a small stream coming down a rocky wash from a canyon on the east face of the Victoria Mountains. Low broad-topped oaks with massive trunks sometimes 2 feet in diameter are common in the valley at Miraflores, and the scenery reminded us of places in the live-oak belt of Californian valleys. Miraflores is the point whence Mr. Belding made his visit to the Laguna Mountains in 1883, and we secured the services of the same guide, Francisco Amador.

January 20 we left Miraflores and traveled northwesterly across the gently rising rocky mesa up the course of the Arroyo San Bernardo. For 4 or 5 miles the trail led across the west side of the valley, through an unusually tall and luxuriant growth of giant and other cactuses with numerous species of shrubs and small trees, mainly tropical species, which form a jungle all the way to the base of the mountains. There we entered an open canyon, the bed of the stream being very broad and covered with masses of water-worn bowlders of all sizes, evidences of the floods which sometimes sweep down these slopes. The trail up the canyon was extremely rough and broken, leading repeatedly back and forth across and along the bowlder-strewn bottom or up and down the densely brush-grown sides. A few cottonwoods of a species peculiar to these mountains with conspicuous white bark were scattered here and there along the canyon, and in flats along the sides were small patches of corn. About 13 miles from Miraflores we camped at an altitude of about 1,500 feet at San Bernardo, a small milk ranch where two families were living. A little land is cultivated here and a small quantity of cheese is made.

January 21 we continued westerly some distance up the canyon and then turned to the right in a northerly direction and crossed two high sharp ridges and numerous smaller and more rounded ones forming the eastern slope of this section of the main range of the Victoria Mountains. From San Bernardo the mountains became much steeper and rougher. The more rounded ridges and depressions were covered with low broad-topped oaks so closely set in many places that it was difficult to find a passage. These oak thickets were irregularly placed and intermingled with open park-like grassy areas. From the tops of the highest ridges, from 4,500 to 5,000 feet altitude, we had fine views of both coasts of the peninsula and the intervening country. In the afternoon, after traveling about 14 miles in a generally northern course from San Bernardo, we came to a long abandoned milk ranch called El Sauz. It was at an altitude of about 4,600 feet in a little flat at the bottom of a steep-sided canyon, where a small stream of clear cold water and plenty of wood and grass completed the requirements for a beautiful camp. Scarlet-fruited shrubs (*Heteromeles*) and a few tall cottonwoods grew along the stream, two species of oaks and a madroño formed irregular patches on the northerly slopes, and there were open grassy areas, mainly on summits and southerly slopes, where the sotol, agaves, and yuccas were abundant. We remained here for two days to do our first work in the Victoria Mountains.

January 24 we left El Sauz and followed the trail down the slope to another deserted milk ranch in a pretty flat, in the bottom of a tributary oak-grown canyon. Here the trail turned, crossed a high ridge to the north, and descended part way on the farther side to a little knoll where a small stream issues from a side gulch. This place, 8 miles from El Sauz, has an altitude of about 5,000 feet and is called La Chuparosa, or the Humming Bird. Many deer tracks were seen along the route and Viosca's pigeons were common and nesting in the live oaks. The heart-breaking work up and down the very steep slopes was telling on our animals, so we were compelled to camp at La Chuparosa.

January 25 we continued northerly, the trail leading along the summits of two high and extremely narrow ridges which form the crest of this part of the range. Between these ridges a large canyon heads close to the summit and a small stream, the Arroyo de San Antonio, flows down the easterly slope to the gulf, passing Santiago village. The point where the trail crosses this stream is an old camping place called San Antonio. The crest of the second ridge immediately north of San Antonio was so narrow in places that there was little more than room for the trail, the mountain dropping away precipitously several thousand feet on the west and having a very steep slope on the east. North of this sharp ridge the mountain top broadened and the trail led down a long north slope thickly overgrown with a forest of pinyon pines and small oaks into the basinlike mountain valley of La Laguna, where we camped at the ruins of an old

ranch in the extreme upper end. This open, nearly flat-bottomed valley is about a mile long and from one-fourth to one-half as wide with several small brooklets uniting near the upper end and flowing down the middle. It is situated at an altitude of about 5,500 feet and surrounded by steep mountain slopes covered with low oak and pinyon forest. Formerly the bottom of the valley is said to have been occupied by a shallow lake, the lower end of which was eroded during a season of heavy rains and the lake drained. This occurred many years before Belding's visit here in 1882, yet some of the people at La Paz and elsewhere in the cape district still believe the lake exists. Two or three miles by winding trail and half this distance in a direct line westerly from La Laguna lies La Aguja, a sharp needle peak of granite over 6,000 feet high standing out boldly as the northwestern end of the Laguna Mountains and presenting a precipitous front 5,000 feet high to the lowlands between La Paz and Todos Santos.

La Laguna Valley, from which the immediately surrounding group of mountains takes the name of Sierra de la Laguna, is a notable point from the fact that it is rich in species of plants, birds, and mammals peculiar to the cape district and is the type locality for many of them. Frazar, Belding, and others have made notable collections here. We remained in this camp until the morning of January 29, when we started on our return to La Paz. We crossed the northern rim of the valley and then for three hours descended a long, steep, and narrow ridge leading down the north end of the mountain range. The trail was an old one and apparently had not been used for years. It would have been nearly or quite impossible to ascend it, owing to washouts along some of the steepest slopes, down which our animals were forced to slide in a half-sitting position. In many places it was obstructed by trees and bushes which had grown in or across the trail. This abrupt and continuous descent for over 3,000 feet brought us to a deserted ranch on the bank of a small creek in the flat bottom of a deep canyon, so densely grown up with bushes and small trees that we had trouble in forcing our way across. The trail led directly across the canyon and 1,500 feet up the abrupt and rocky slope on the opposite side to the crest of the ridge. The top of this ridge is very narrow and on the farther side drops into a deep, rugged box canyon in which there is an abundant growth of vegetation. (See Pl. 19, Fig. 2.) The trail here turned abruptly to the left and followed down the crest of the ridge for several miles, finally bringing us to the bottom, where the canyons on the two sides of the ridge, both carrying small creeks, unite. Here we found two men cutting fan palm leaves for thatch and they both left their work and went half a mile down the canyon to show us where the trail is forced up on the steep mountain side to the right by the broken character of the canyon bottom. Up on the mountain side the trail soon led into a side canyon and down it to the main canyon again, below the rough stretch we had avoided, and brought us out at El Taraiso, a small ranch containing two or three families. We camped here at an altitude of about 1,800 feet after traveling about 14 miles of excessively difficult and broken trails, which were extremely exhausting to our stock.

We were now out of the roughest part of the mountains and on January 30 followed a good, broad trail for 10 miles northeasterly through low hills and ridges to the small mining camp of El Valle, where an American company was working a small stamp mill and concentrating plant. Eight miles beyond this in the same direction, along a good wagon road, through open rolling hill country we came to the mining town of El Triunfo at an altitude of about 1,800 feet among rounded hills. This was formerly the largest and most thriving mining camp in the peninsula, but at the time of our visit was working on a much smaller scale. The large reduction plant and a huge pile of tailings at the border of the well-built little town gave evidence of its former prosperity. Rain began soon after our arrival and continued all night. The following day, January 31, the rain continued and I took the stage for La Paz, leaving Goldman to follow with the pack outfit. The distance is about 30 miles on a good wagon road, but owing to the worn-out condition of the animals Goldman did not arrive until the following day, February 1. This ended our overland work. From February 1 to 5 we worked about La Paz and on February 6 left that place on a small pearl-fishing boat, with a crew of three men, to visit Espiritu Santo Island, off the mouth of La Paz Bay.

February 7 we reached the island, about 20 miles from La Paz, and anchored in front of a few houses in a small bay on the west side, where a company organized at La Paz was experimenting in raising pearl oysters. They had several beds planted and claimed to be getting gratifying results. Espiritu Santo is a waterless volcanic island covered with rounded hills and mesas where a nearly black jack rabbit has developed, evidently from the same stock as the pale form living a few miles away on the adjacent mainland. A few mangroves occupy a small tidal lagoon at the head of the bay.

February 8 we left Espiritu Santo and sailed southeasterly to the southern end of Ceralvo Island, which is waterless and uninhabited. Owing to calms and head winds we did not reach Ceralvo until February 11. The only good landing and comparatively level land on this island is at its southern end; the rest of its shores are abrupt and rocky.

February 13 we left Ceralvo, reached La Paz on the 15th, and sailed on the steamer for Ensenada February 19, arriving at that place on the 26th.

February 28 I proceeded to San Diego in a gasoline launch, while Goldman made the journey overland by stage. The stage road from Ensenada leads northerly along the coast about 7 miles to Sauzal, a ranch, facing the sea, which was at that time the home of Mrs. Robert Louis Stevenson. From this point the road led a few miles up Sauzal Canyon, passing through the fertile Guadalupe Valley. From this valley the road followed up the Canyon del Burro to the top of a ridge, said to be the highest point on the road between Ensenada and San Diego, and descended to a little valley called Vallecitos. Beyond this another low ridge was crossed and then the Canyon de Cancio descended to a ranch of the same name about 55 miles from Ensenada and the regular stopping place for the night. All hills along this route have rather gentle rounded slopes; a little farther inland are ridges rising 1,500 to 2,000 feet higher than the road which are a continuation of the coast range back of Ensenada. The hills along the road are mainly granite and dotted with bowlders of the same material. Large oaks (*Quercus agrifolia*) are numerous in the canyons, but the hill slopes facing the sea are nearly bare. In some of the valleys there was a thick growth of arrow weed (*Pluchea sericea*), but the bordering hills above 1,000 feet were usually covered with a dense growth of chamiso (*Adenostoma*).

March 1, Goldman left Canyon de Cancio and traveled about 40 miles, mainly along or near the Tijuana River, to Tijuana, whence he took a train and joined me at San Diego, where the expedition ended.

PHYSICAL CHARACTERISTICS.

Lower California is a long, narrow peninsula, washed on the west by the Pacific and on the east by the Gulf of California, or Sea of Cortez, as it was named by the Spaniards. The peninsula extends in a southeasterly direction from the southern border of California, following the general direction of the west mainland coast of Mexico, and measures about 800 miles long by from 30 to more than 100 miles in width. The peninsula as a whole is an arid desert, a large part of which is subjected to long-continued droughts.

Lower California, while mainly a desert, exhibits a number of striking contrasts. The tops of the higher mountains in the northern and southern ends of the peninsula are covered with forests. In the north the yellow pine predominates and the mountains are capped with snow in winter, while on the eastern side the rugged and precipitous slopes rise from the excessively hot basal plains, supporting remarkable growths of cactuses, yuccas, and many other desert plants. In the south-central section great lava-crowned plateaus are gashed by deep-walled canyons, which are occasionally watered by small streams producing lovely oases where flourish an abundance of subtropical fruits. The country is everywhere scored by rock-strewn and sandy washes, ordinarily dry, but marking the drainage courses of occasional torrential flood waters. The Colorado, one of the great rivers of the continent, flows into the head of the gulf and supplies water to irrigate the marvelously rich alluvial lands bordering its delta.

A single main chain of mountains extends from the northern border southeasterly to La Paz Bay, a distance of nearly 700 miles, and dominates the peninsula. It is an extension of the mountain system of southern California, and forms a continuous series of ranges varying in

Fig. 1. Camp at La Chuparosa, in live oak forest. Upper slopes of Sierra de la Victoria, south of La Laguna.

Fig. 2. [illegible]

FIG. 1. –Santa Anita ranch in valley of San Jose del Cabo.

FIG. 2.—East slope of Cerro Mayor, the highest peak in the Cocopah Mountains. This is a typical desert range.

length and altitude but lying generally parallel to the gulf coast. This mountain chain forms the crest of an interior plateau, the northeastern, or gulf front, of which is composed of a series of high, precipitous escarpments, while the slope to the southwest is long and gradual. The escarpments of the gulf side appear to be the result of a long series of fault lines, along which the mountain slopes rise abruptly either from the low basal mesas, from the borders of narrow coastal plains, or directly from the shore of the gulf. Where basal mesas are present they slope gently from the foot of the escarpment to the gulf, scored by deep box-walled dry canyons and terminating, like the mesas near Santa Rosalia, in a precipitous front on the shore. In other places the mesas, as well as some of the coastal plains along the gulf, are broken by barren hills, ridges, and low mountains.

The highest part of the main range begins on the northern border near the middle of the peninsula and extends southeast about 150 miles, swinging gradually nearer the gulf coast, which it closely approaches near the thirtieth parallel of latitude. This part of the main range includes the Sierra Jaurez and the San Pedro Martir Mountains, which are the highest of the peninsula, ranging from 4,000 feet near the California border to more than 10,000 feet altitude on La Providencia Peak. From near the thirtieth degree of latitude to La Paz Bay the main mountain ranges lie along the gulf coast wholly within the eastern third of the peninsula.

The continuity of the main chain from the border to La Paz Bay is broken by several passes varying from 1,200 to 3,200 feet in altitude. The only great break in the mountain chain of the entire peninsula, however, is that opposite the head of La Paz Bay, where a pass more than 15 miles broad and probably less than 200 feet high at its lowest point completely separates the main ranges to the northwest from those to the southeast.

Southeast of La Paz Bay there is a reversal of the relations of the mountains to the coast, and the main range there extends along the Pacific coast, to which it presents a high, precipitous escarpment a few miles inland with a basal slope extending to the shore with a long easterly slope, broken by secondary mountains, between the crest of the range and the gulf. The main mountains lying southeast of La Paz are second in height only to the ranges near the northern border, varying from 3,500 to 8,000 feet in altitude. The intermediate mountains, between the southern end of the San Pedro Martir Range and La Paz Bay, vary in altitude from 2,500 to 4,000 feet, with scattered peaks reaching altitudes of from 5,000 to 6,000 feet. It is of special interest to note that the high main range southeast of La Paz is of pale gray, rapidly disintegrating, granite closely similar in appearance to that of the high main range near the northern border.

In the north, where the main chain lies near the middle of the peninsula, it is paralleled along both coasts by much lower and more broken subordinate ranges. Beyond 150 miles south of the border the subordinate ranges on both coasts lose their identity, the one on the gulf shore blending with the main chain where the latter approaches the coast beyond Point San Fermin, and that on the west swinging toward the middle of the peninsula south of the Salado River, and thence southward lying close along the west base of the main chain, with which it merges east of San Quintin Bay.

In places along the main chain south of the San Pedro Martir Range short offsetting spurs and ridges occur on either side of the ranges following the same general course and usually inclosing small valleys or plains between them and the main ranges. Throughout their extent the ranges are scored by many canyons, especially on the gulf side, in some of which occur small permanent streams of excellent water.

In a general way, from the northern border southeasterly for a distance of about 700 miles to La Paz Bay, an irregular plateau of varying elevation occupies the westerly two-thirds of the peninsula. Its highest elevations are near the top of the main range, sometimes at the very summit, immediately beyond which descends the sharp declivity that forms the gulf slope. In other places the upper border of the plateau rests against the westerly flank of the narrow culminating ridges of the range. The character of the plateau is well shown near the northern border on the Sierra Juarez, where its summit is formed by the plateau which descends gradually for

miles to the west and on the eastern front drops precipitously several thousand feet. The prolonged western slope of the San Pedro Martir Mountains and the precipitous eastern slope are also strong characters of this range, but its greater elevation causes a far more rapid western slope than usual in the peninsula. From near the southern end of the San Pedro Martir Range to near Calmalli the plateau is lower but well marked, as it is also in the great lava-capped region from south of Calmalli to La Paz Bay.

The elevation of the plateau varies from 6,000 feet on the Sierra Juarez, and seven to eight thousand feet on the San Pedro Martir Range, to 1,000 feet or less near the middle of the peninsula. In addition to the differences in its elevation, the surface of the plateau is varied by small, scattered mountain ranges, isolated mountains, hills, ridges, and mesas, as well as by many intervening plains, valleys, basins, and dry watercourses. For some distance along the north coast the plateau is cut off from the shore by narrow ranges of coast mountains; farther south here and there it is limited by the inner borders of low, nearly level coastal plains, as by the San Quintin plain, the Vizcaino Desert, and the Magdalena Plain. Between these coastal plains the plateau ends along the shore in low, descending ridges, broken hills, and scattered mountain ridges varying from 100 to 2,500 feet high. These are two unrelated to be considered as forming parts of a definite range. From near Cape San Eugenio to near Ballenas Bay the ridges and peaks of the Sierra Vizcaino, lying a few miles inland, form the only definite coastal range from San Quintin to beyond Magdalena Bay. This short range is completely isolated and appears to be unrelated to the coastal mountains farther north.

Owing to the width of the western plateau slope the usual view to the east from the Pacific coast or the coastal hills is over a broad, rising and broken plain which culminates in a high skyline of serrated peaks or in the long horizontal line of the swelling plateau surface which cuts off the hills behind. From the east coast the view inland is strikingly different, the precipitous fronts of the main range rising near at hand or only a few miles inland.

West of the summit of the Sierra Juarez a series of small valleys with scattered, intervening hills and low mountains occupy the plateau, with small coastal ranges limiting most of its seaward border. South of this, along the west and south base of the San Pedro Martir Range, the plateau is far more mountainous and broken, but becomes more undulating and regular as it approaches the coastal plain of San Quintin.

From the plain of San Quintin and the southern border of the San Pedro Martir Mountains to the northern side of the Vizcaino Desert, near Calmalli, the high interior of the plateau is undulating and irregular, varying from 1,200 to 2,500 feet in altitude and largely occupied by a series of small open plains, including the Llano de los Buenos Aires, the Llano de Santa Ana, and many smaller valleys. These valleys are bordered and more or less broken with barren ridges and scattered mountains, while the descending border of the plateau in some places reaches the Pacific coast as rounded or flat-topped ridges separated by deep, dry washes; elsewhere the plateau is limited along the coast by low, rocky ranges and scattered hills. Some of the hills and mountains at various points in this section of the plateau have a flat, or mesa, top. Perhaps the most striking of these is the Mesa de San Carlos. To the southeast this section of the plateau descends and gradually merges into the low, nearly level plain of the Vizcaino Desert. North of San Fernando rises the isolated Cerro San Juan de Dios, the highest mountain on this part of the tableland and said to be the southernmost mountain on the peninsula on which snow falls.

The major part of the main mountain chain and bordering tablelands from the northern border to near Santa Gertrudis, southeast of Calmalli in about 28° N. latitude, as well as a large part of the coastal mountains on both sides in the north, are of pale gray and easily weathered granite with a few scattered areas of low volcanic peaks and ridges and of other geological formations.

The main range south of La Paz Bay, as already noted, is on the Pacific side of the peninsula, and is formed by a series of high granite ridges, culminating in sharp peaks or narrow ridges from 3,500 to about 8,000 feet in altitude. Everywhere among the granite mountains the disintegration is very rapid, as evidenced by the vast sloping accumulations of sand, gravel,

and bowlders, often of enormous size, on the plains along their bases and especially at the mouths of large canyons. Some of the granite mountains of the coastal ranges east of the Sierra Juarez and San Pedro Martir Mountains, in one of the most arid parts of the peninsula, are almost buried in the sloping mass of their own débris and are typical examples of "buried" mountain ranges. At the mouths of many large canyons, notably at the east base of the San Pedro Martir Mountains, enormous alluvial fans or deltas exist, some of them hundreds of feet deep and several miles broad. These are of still greater length where they descend to the bottom of the adjacent valleys. They are more fully described in the accounts of the various ranges.

From a little south of the old Mission of Santa Gertrudis to La Paz Bay the main chain of mountains and the surface of the interior plateau is almost entirely volcanic, overlying an elevated sandstone formation. These volcanic mountains are extremely rugged, and the southwestern slope of the mountains and the plateau are scored with numerous deep and often rugged canyons. The surface of the great lava-covered plateau is broken by numerous volcanic hills and peaks, including many old craters, and descends to the coastal plains which border the Pacific for hundreds of miles in this region.

The highest of all the volcanic peaks of the peninsula, El Puro Año, has an altitude of about 6,800 feet and is located at the southern end of the Sierra Santa Lucia; next to this are the Tres Virgines, situated a little farther north, with an altitude of more than 6,500 feet. The Tres Virgines are the most recent of the volcanoes, one of the peaks having shown signs of activity within a few years. In addition to these mountains forming part of the great volcanic region of the southeast a few other smaller areas occur here and there, notably alongshore at San Quintin Bay and on coastal islands, including San Martin and the San Benitos, the Sierra Santa Clara on the west side of the Vizcaino Desert, and the Sierra Pinta near the mouth of the Colorado River.

As already noted, the general slope of the western two-thirds of the width of the peninsula is westerly or southwesterly directly to the Pacific coast, nearly at right angles to the main mountain ranges. As a result there are no long drainage courses, the longer of them extending from 25 to 50 miles. Most of the drainage channels are dry throughout the most of the year, except for occasional floods, and sometimes during several years in succession.

The coast line exceeds 2,000 miles in length, more than half of which is rocky and broken, consisting either of low bluffs formed by the precipitous borders of tablelands descending from the interior or the eroded slopes of hills and mountains which often rise from the sea in bold cliffs and headlands. Much of the eastern, or gulf, coast is more or less closely bordered by the main mountain chain, giving it a generally more rugged and broken character than that of the western coast. The southern half of the gulf coast and the many adjacent islands are notable for their bold and often precipitous shore lines with the contours weathered and sculptured into strange and picturesque forms, which have been likened by one author to "castles, towers, peaks, and massive lines of fortifications." [1] The gulf shore, however, is also varied by a number of coastal plains, mainly of limited extent, such as those at Punta Arena (south of Ceralvo Island), Ventana Bay, La Paz, Loreto, Mulege, and San Felipe. The northern half of the gulf coast, from a short distance south of Santa Rosalia northward nearly to San Felipe Bay, is mainly abrupt and commonly formed either by lines of precipitous bluffs, the fronts of low tablelands which extend back a few miles to the main mountain ranges, or by rugged lines of hills and mountains broken at wide intervals by narrow belts of lowland. San Felipe Bay is half-moon-shaped with lines of low sand dunes about its southern and western shore and a high rugged hill of black rock on its northern side forming San Felipe Point. Thence to the mouth of the Colorado the shore line is low and gently sloping.

The west coast of Lower California, while less rugged than that of the east, is largely rocky and broken, being fronted by the wave-worn bases of hills and low mountains alternating with the precipitous fronts of low table-lands, spaced here and there by broad coastal plains where the table-lands and mountains retreat to the interior. The principal coastal plains on the Pacific side lie back of San Quintin Bay, near Scammon Lagoon, and opposite Magdalena Bay.

[1] Seemann, Voyage of the *Herald*, II, p. 155, 1853.

The northern part of the western shore line for more than 100 miles south of the boundary is abrupt and rocky, being fronted mainly by rocky hills and low mountains, forming parts of a low coast range rising 2,000 to 4,000 feet above the sea. Near San Telmo the mountains swing back farther into the interior and the immediate coast line is lower, but beyond the San Quintin Plain it is broken by the precipitous fronts of low mountains and mesas until the northern border of the Vizcaino Desert is reached. From the vicinity of Cape San Eugenio, the Sierra Vizcaino parallels the coast a short distance inland to near Ballenas Bay. Thence southward to within about 75 miles of Cape San Lucas the mountains give way to a low coastal plain except from south of San Ignacio Lagoon to opposite Comondu, where the plain is interrupted by low rocky hills or the borders of low table-lands.

The shore of the southern end of the peninsula from 15 miles south of Todos Santos to San Jose del Cabo is formed mainly by granite ridges varying from 100 to 500 feet high, which descend from the mountains a few miles inland and form a series of narrow rocky capes. Between the capes are small half-moon bays, commonly with white sand beaches about their heads. Cape San Lucas, the most prominent of these projecting points, constituting the southernmost tip of the peninsula, is a ridge nearly 300 feet high forming a bold, narrow headland extending into the sea with outstanding sugar-loaf rocks just off the point. On the shore end this ridge descends to a beach backed by a belt of sand dunes which separate it from a continuing but higher ridge extending inland toward the mountains. The Cape ridge forms the western side of the shallow San Lucas Bay. A sandy plain slopes from the mountains a few miles inland to the north down to a flat where San Lucas village is located just back of the sand dunes along the shore of San Lucas Bay. Another jutting granite ridge forms the other side of the bay about a mile east from the cape.

In addition to the considerable number of small half-moon bays around the entire coast line a number of bays and harbors are much larger, as those at Ensenada, San Quintin, Vizcaino (the largest of all, from which open the Black Warrior and Scammon Lagoons), Ballenas, and Magdalena on the Pacific coast and La Paz, Concepcion, and Angeles on the gulf coast.

The gulf shore is without any long, mangrove-bordered lagoons, although about the head of La Paz Bay and in a few other limited areas mangroves occur as far north as the village of San Lucas, a few miles south of Santa Rosalia. A series of long, narrow, mangrove-bordered lagoons border the west coast from the east side of Margarita Island north to San Jorge and some small areas of mangroves also occur near Cape San Lucas. The only grassy tidal marshes on the coast of the peninsula appear to be about the head of San Quintin Bay and lesser ones a few miles southward beyond the mouth of San Simon River.

Salt deposits exist on the coast near San Quintin Bay and especially large ones near the heads of Scammon Lagoon, near the head of Ballenas Bay, and on Carmen Island. (See Pl. 21, Fig. 1.) Another deposit is located on the shore of the gulf between the mouth of the Colorado River and San Felipe Bay.

NOTES ON THE RECENT GEOLOGICAL HISTORY OF THE PENINSULA.

Both shores of Lower California bear many signs of extensive erosion in the form of wave-worn cliffs and narrow rocky points. In addition most of the coastal islands are similarly eroded and closely match the neighboring shores in geological structure and often in surface contours, while the intervening waters are so shallow it is evident that they were once joined to the shore; Todos Santos, Cedros, and Espiritu Santo Islands are especially striking illustrations of this former connection. Espiritu Santo, in front of La Paz Bay, forms a continuation of a point on the mainland with which it is joined by a submarine ridge covered by only 8 fathoms of water at the deepest point of the 4-mile channel separating them. The surface contours and structure of the cliffs on the two sides of this channel show the closest relationship. If the peninsula formerly included, as appears probable, most of the bordering islands, it must have been far broader than at present, but the general outline was not otherwise much different. Most of the islands on both coasts are very rocky and hilly or mountainous, but the long northern end of

Fig. 1.—Salt bed on east side of Vizcaino Desert, west of San Ignacio. The salt is so pure that it is gathered by natives for domestic use.

Fig. 2.—Mud volcano near Volcano Lake, in delta of Colorado River. The mud is now dry and cracked. The crater at the left is that of last "eruption" in photograph.

FIG. 1.—Waterhole north of Llano de los Buenos Aires. One of numerous tinajas which store some of the scanty rainfall and render travel possible in these deserts. (Photograph by Dale Bumstead.)

FIG. 2.—Mining onyx on Llano de los Buenos Aires. Onyx from this mine, or quarry, has been shipped to San Diego and distributed to various parts of the United States for many years. (Photograph by Dale Bumstead.)

Magdalena Island is a sandy plain, having been built up by sea sand brought in by currents sweeping along shore.

The connection between the islands and the peninsula within recent geologic time is abundantly indicated by the close similarity in fauna and flora, especially by the bird and mammal life.

The Tres Marias Islands, lying to the southeastward, undoubtedly formed a part of the Mexican mainland at no very remote period. The sea is comparatively shallow between these islands and the mainland, being about 150 fathoms in the deepest part along a submarine ridge extending southeasterly from the islands to the mainland near Banderas Bay. Between the mainland of Mexico and the nearest point of southeastern Lower California as well as between the peninsula and the Tres Marias Islands lies the 1,500-fathom channel leading out from the Gulf of California. The plants, birds, and mammals of the Tres Marias are all either identical with species living on the adjacent Mexican mainland or obviously derived from them. On the other hand, while a strong infusion of species of plants plainly derived from the Mexican mainland exists in Lower California, the flora as a whole is more closely related to that of the deserts of southern California, Arizona, and northwestern Sonora, while the batrachian, reptile, bird, and mammal faunas are, with rare exceptions, species derived from the mainland to the north.

From the present configuration of the land surface it is evident that an arm of the sea once extended across the peninsula through the broad low pass from the head of La Paz Bay to the Pacific, thus forming an island of the mountainous region lying south of La Paz. La Paz Bay appears to be the remaining part of this channel. When viewed from La Paz or from the west coast the islandlike appearance of the mountain area to the south is very striking. The existence of this area as an island could not have been greatly prolonged judging by the uniformity of its fauna and flora with that of the peninsula farther northward.

The present contours show that the sea formerly extended inland from the head of Vizcaino Bay, covering all the broad Vizcaino Desert and probably across to the gulf by way of the low plateau on which is located San Ignacio, and which extends as a nearly level pass between the Tres Virgines volcanoes and the north end of the Sierra Santa Lucia. The submergence of the Vizcaino Desert area must have made a long narrow island of the Sierra Santa Clara and Sierra Pintada, which together form the Sierra Vizcaino. The trend of the Sierra Vizcaino and of the mountains on Cedros Island indicate that at one time they may have been united in one continuous range, probably before the submergence of the Vizcaino Desert.

Many of the other islands about the shores of Lower California evidence by their position and formation relative to the adjacent shores that they were once the points of capes on the mainland which have been cut off from the shore and sometimes subdivided into two or more sections or islets. The Todos Santos Islands, at the mouth of the bay at Ensenada, were evidently once united and formed a continuation of Punta Banda, with which they are still connected by a submarine ridge. The mountainous southern end of the Magdalena Island and the mountain at Cape San Lazaro on the same island were once separate islands which have been joined recently by a broad sandy plain built by ocean currents and winds to form the long, narrow and flat sandy northern three-fourths of this island. The northern and eastern mainland shores of Magdalena Bay are low and sandy and much of the northern end of the bay is very shallow, being filled in with sand. This sand formation extends north from the bay along the coast nearly 100 miles and appears to be supplied by the ocean current alongshore. Santa Margarita Island appears to have been divided by a narrow arm of the sea into two small mountainous islands. The entire Magdalena plain is so low and nearly level that it appears probable that it also was submerged at the period when the sea occupied the pass at the southern end of this plain, near La Paz. From such facts it appears that the peninsula was partly submerged and then arose slowly with approximately the outline it posseses to-day but considerably greater in extent. Since then it appears to have been steadily reduced through erosion by the sea.

The apparent exception to this is the northern two-thirds of Magdalena Island, which appears to be still growing by additional sand brought by the sea, and the gradual increase of land area in the delta of the Colorado River through the enormous deposits of silt carried down by this

stream from the middle of the Rocky Mountain region. Signs of rapid erosion are everywhere about the shores of the peninsula and of the adjacent islands.

Dr. Eisen credits the great deposits of bowlders and wash material along the eastern base of the Sierra Victoria and near San Bartolo to glacial action.[1] After seeing the enormous masses of huge bowlders and other material carried down by floods and deposited at the mouths of canyons along the east base of the San Pedro Martir Mountains, I am inclined to credit the deposits along the east base of the Sierra Victoria to a similar origin rather than to glacial action. Our route, however, did not take us near the "moraines" seen by Dr. Eisen between Miraflores and San Bartolo, the most notable of which at the mouth of the canyon of San Bartolo are known as the Quebrados de San Bartolo. Nowhere during the entire expedition did I see any signs of glacial action, and these "moraines" appear to require further examination to determine their origin.

The partly buried mountains in the northeastern part of the peninsula, the huge bowlder masses on the higher parts of the Sierra Juarez and San Pedro Martir Mountains are striking evidence of the rapid erosion now in process. Other indications of this action are presented by the flat-topped mesas existing at various points on the western slope from near Cape Colnett south to the middle of the peninsula, including the Mesa de San Carlos, which rises high above the surrounding levels and is several miles across. In addition numerous lower table-topped elevations rise from the higher base level of the interior. The granite formation which occupies most of the northern half of the peninsula as well as the granite range south of La Paz are notable for their rapid disintegration, as shown by the vast quantities of granite, sand and gravel, which cover the slopes of these mountains and the adjacent plains.

MOUNTAINS OF THE NORTHERN INTERIOR AND MIDDLE GULF COAST.

Sierra Juarez and San Pedro Martir Mountains.

The northern part of the main mountain chain of Lower California is formed by the Sierra Juarez-San Pedro Martir Mountain groups. These mountains are a direct continuation of the San Jacinto Range of southern California. They are composed mainly of the same pale gray, rapidly disintegrating granite, and their eastern front, overlooking the desert, is a gigantic rocky escarpment thousands of feet high, while the western slope is long and gradual. In all of these characters these ranges bear a close resemblance to the southern end of the Sierra Nevada in the Mount Whitney section.

The Sierra Juarez and San Pedro Martir Mountains have so much in common they may be considered as forming a single range about 175 miles long, extending from the northern border of Lower California southeasterly, lying a little to the east of the middle line of the peninsula. About a hundred miles south of the border the range is divided by San Matias Pass, a deep notch which has an altitude of about 3,200 feet. (See Pl. 2, Fig. 2.) The part of the range north of this pass is the Sierra Juarez (the northernmost section of which is locally often called the Laguna Hanson Mountains or the Sierra Juarez) and that to the south the Sierra San Pedro Martir, or San Pedro Martir Mountains, which latter have a length of about 75 miles. The crests of both sections are in the form of long, high ridges but little broken by projecting peaks, and varying from 4,500 to about 9,000 feet in general altitude.

The east base of these mountains rises from desert valleys or plains, the surfaces of which, broken by scattered mountains, extend to the lower Colorado River and Gulf of California, the plains varying from about 1,500 feet down to sea level. From these plains, often with only a narrow belt of low foothills or a talus slope, the precipitous rocky front of the range rises boldly 3,000 to over 8,000 feet. The front of this great escarpment is scored at intervals by narrow, rough-walled canyons which have carved a few outstanding peaks or ridges from the bald rock walls. La Providencia Peak, in the San Pedro Martir Mountains, is the only one of these frontal peaks which rises prominently above the general elevation of the mountain mass behind it.

[1] Proc. Calif. Acad. Sci., V, p. 754, 1895.

The western slope usually descends gradually through a broad belt of rounded foothills to bordering elevated valleys and tablelands beyond which are coastal mountains. That part of the summit rising above 4,500 feet in the Sierra Juarez and about 6,000 feet in the San Pedro Martir Mountains is occupied by the only yellow pine forests in Lower California.

A wagon road follows the Sierra Juarez from Campo, just north of the border, to a few miles south of El Rayo ranch, where it descends to the valley on the west side of the range. Another wagon road crosses the range from Alamo Plain to Mexicali on the Colorado Desert through a narrow pass northeast of the old mission of Santa Catarina, where a small Indian village still exists. This is approximately the route by which Pattie and his companions reached the west coast from the Colorado in 1827. Another branch of the wagon road from Ensenada leads across Alamo Plain and through the range at San Matias Pass to San Felipe Bay on the gulf. Below are more details concerning the main sections of this northern part of the main range.

Sierra Juarez.

These mountains consist of a single main ridge, varying in height from about 4,000 feet at the northern border to about 6,000 near Hanson Lagoon, and thence down to 4,000 or 5,000 feet near the southern end, where it finally descends rapidly to San Matias Pass. The northern half of this range is known locally as the Sierra del Pinal or Laguna Hanson Mountains. The highest part of the main mountain mass is near Hanson Lagoon, but the highest peak, Cerro Colorado, in the southern part of the range, near Santa Catarina Mission, has an altitude of about 6,677 feet.

The summit of the northern part of the range has a width of only 3 or 4 miles across the widest part. It forms a long, narrow, gently rolling plateau, which breaks down abruptly into bare granite cliffs on the east and descends through gently sloping foothills on the west. Along our route up the west slope from La Huerta to El Rayo ranch the trail traversed a distance of about 18 miles over such gradual slopes and rounded ridges that we seemed to be crossing an undulating plain until near the summit, when the higher ridges became somewhat more marked. This slope is covered with gravelly decomposed granite varied by low projecting granite ridges and large bowlders, and is drained by shallow washes and gulches.

The highest part of the plateau summit, near Hanson Lagoon, is broken by many small granite ridges, knolls, and piled masses of titanic granite bowlders, 50 to 300 feet high, with pretty parklike forested basins and flats between.

The old Laguna Hanson ranch, or El Rayo, as it is now called, lies on the summit of the high part of this range northeast of Ensenada. Southeasterly from this ranch the summit of the range becomes lower and more broken, and the wagon road along the summit from the northern border swings down the west slope, which becomes much more abrupt until throughout the last 20 miles or more north of San Matias Pass it rises abruptly from Alamo Plain and presents lines of cliffs and steep slopes forming the flanks of long table-topped mountains, upon one of which rises Cerro Colorado.

The Indian village near the site of the old mission of Santa Catarina lies at the west base of this steep escarpment about 20 miles northwest of San Matias Pass. This latter is a deep, narrow, troughlike notch, where the eastern and upper end of Trinidad Valley cuts through the mountains to the low desert valley on the east.

Water is scarce all along the summit of the Sierra Juarez. The Hanson Lagoon (or Laguna Hanson), about half a mile across, is the largest of several small shallow lakelets lying on the highest part of the range northeast of Ensenada. A few very small streams rise at the heads of gulches near the top of the west slope and flow down to the lower border of the foothills in the northern two-thirds of the range but are fewer in the southern third. Water is still scarcer on the higher parts of the east slope than on the west, but occurs lower down in most of the large canyons near the desert. El Tule Arroyo and Arroyo Grande flow out from the east base of Cerro Colorado and are the largest and most permanent streams on the east side of this range.

San Pedro Martir Mountains.

The San Pedro Martir Range is the highest and most notable mountain group in Lower California. It is almost entirely of pale gray granite and extends about 75 miles southeast from San Matias Pass, in direct continuation of the Sierra Juarez. The range rises rapidly at first in a series of narrow, crested ridges, reaching an altitude of over 7,000 feet on Salvatierra Peak a few miles south of San Matias Pass, and increasing in altitude and width for about 20 or 25 miles to its culmination at an altitude of over 9,000 feet on the main ridge and to approximately 10,126 feet on La Providencia Peak, the highest point on the peninsula. Beyond this the range gradually descends and narrows until it merges and is lost in the crest of the Matomi section of the broad interior plateau as detailed below. The broadest part of the summit of the range measures about 6 or 8 miles across opposite La Providencia Peak and about twice as much across the base. The peak is situated in the middle of the east front of the San Pedro Martir Mountains and is a sharp, narrow rocky crest rising like a cock's comb on the end of a high granite ridge carved from the rocky front of the mountain by the tremendous gorge of Canyon Diablo. This canyon rises on the west side of this crest and extends first northerly and then to the east and has the form of a gigantic ragged gash in the mountain. The crest extends northerly from its base, the peak being at the northern extremity. The east side of the crest and peak forms part of the east wall of the mountain range, facing the desert.

La Providencia Peak is also called Santa Catalina, Calamahue, and La Encantada on various maps. It is a bold landmark for more than 100 miles in all directions across the deserts east of the range and becomes especially notable in winter when covered with snow. Owing to the high intervening ridges it is not visible from the land on the Pacific side, but it is said that its snowy summit may be seen for more than 100 miles at sea.

The eastern side of the San Pedro Martir Mountains forms the highest and boldest part of the abrupt escarpment already described. Here the bare granite cliffs rise directly from the basal valley in a series of great rock slopes for from 4,000 to over 8,000 feet. All the higher crests and summits of the range, including La Providencia, are located close along the top or only a short distance back of this high escarpment.

The main part of the east front of the range is scored by four great canyons, all of which contain small permanent streams. Beginning with the northern one, these are La Esperanza, 10 miles south of San Matias Pass; El Diablo, 6 miles farther south (at the base of La Providencia); La Providencia, about 6 miles beyond; and Santa Rosa, about 8 miles still farther south. These canyons are notable for the great alluvial fans which spread over the plains from their mouths. Southeasterly other canyons occur in the front of the high mountain plateau which continues the end of the range as described below.

The western slope of these mountains, while much more gradual than the eastern, is high and abrupt with sharply ridged foothills, especially in the northern half. The middle of the range is there scored by numerous canyons which contain the headwaters of four main streams draining to the Pacific—the San Rafael, San Telmo, Santo Domingo, and San Simon. All of these have permanent water in parts of their courses, but the Santo Domingo is the only one which is said to flow continuously to the sea. The higher parts of these mountains are scantily supplied with water in the form of a few small springs and insignificant streamlets.

The summit of the San Pedro Martir Mountains, when viewed from either the east or west side, appears almost as regular and unbroken by projecting peaks as the Sierra Juarez. La Providencia Peak is hidden from the west by the main ridge, about 9,000 feet high, which lies west of the peak, across Canyon Diablo, and when the peak is viewed from the east this same ridge forms a background for it, thus causing it to stand out in comparatively small relief. In traversing the broad central part of the mountains we found the summit subdivided by many rocky ridges and cross ridges with long rocky slopes, often partly inclosing beautiful grassy parklike basins bordered by pine forests. Some of these parks are hanging valleys or plateau-like benches scooped out of the mountain summits at various elevations, with their open sides to the west or south and backed by granite ridges a thousand feet or more high. The intervening slopes are commonly covered with masses of granite bowlders often of great size and here and there form-

ing high, tumbled piles of rock. They are usually so devoid of soil that only widely scattered trees or bushes grow on them. The highest and largest of these basins is called Vallecitos and lies at an altitude of about 8,000 feet near the westerly base of the high ridge which forms the main crest of the mountain, west of La Providencia. To the southeast of this is the little mountain basin of La Encantada, and below, on the westerly slope, at 7,000 feet, lies La Grulla meadow, one of a connected group of beautiful little grassy valleys at the base of bare granite ridges with some small ponds and a small stream along the bottom. The borders of this valley, covered with a thin forest of yellow pines, is dotted with many huge outcropping granite knobs and bowlders, which typify much of the scenery on the summit of these mountains. Farther southeasterly the rolling summit of the mountains becomes lower and narrower until about 10 miles from La Grulla the oval grassy basin of Santa Rosa, about 4 miles long and 2 miles broad, covers almost its entire width and drains through canyons leading down both slopes. A mile southwest of Santa Rosa and nearly a thousand feet below is the benchlike Santo Tomas Valley, and still farther down the same slope, at an altitude of about 5,000 feet, is the bench where the ruins of the old mission of San Pedro Martir are located. About 12 miles southeast of Santa Rosa, at an altitude of approximately 6,000 feet, lies the little valley of Santa Eulalia, marking the southern end of the yellow pine forest.

Southeasterly from Santa Eulalia the range loses most of its mountainous character and gradually descends to the crest of the high interior plateau, along the eastern border of which extends a continuation of the precipitous escarpment fronting the desert and to the west and south a long slope leading toward the Pacific. This plateau has an altitude of from about 3,500 to over 4,000 feet along the crest and forms the southeastern extension of the San Pedro Martir Mountains, uniting them with the higher mountains inland from Point San Fermin, which here approach the gulf coast and continue the main range southward. Three large canyons cut into the east front of this plateau draining toward the gulf have fresh water along their courses before they descend into the open plain. The northernmost is Agua Caliente, southeast of this Paral, and still farther is Matomi. The last appears to be the most important. According to Heller, the Arroyo Matomi is in a wide level valley from 1,500 to 2,000 feet above sea level and walled in by cliffs 1,500 to 2,000 feet high.[1] Here the northern pinyon pines (*Pinus parryana*) appear to reach their southeastern limit in the peninsula. Matomi Peak, with an altitude of about 4,100 feet, lies on the east front of the range near Matomi Valley and appears to be the highest elevation on this part of the peninsular backbone.

A trail used by the early Spanish missionaries leads from the desert at the mouth of Santa Rosa Canyon up across Santa Rosa Park and descends the west slope by Santo Tomas ranch and the old mission of San Pedro Martir. This is the first trail leading across the mountains south of San Matias Pass. Another trail leads up the northwest slope to Vallecitos and still another up the west slope to La Grulla Meadows. The east slope is inaccessible north of Santa Rosa. An irregular, and in places difficult, trail leads along the top of the range from Vallecitos through La Grulla to Santa Rosa and thence to Rosarito ranch near the southern end of the mountains. Owing to the high abrupt slopes on all sides of this mountain group and the broken and rocky character of its summit, it will never be practicable at any reasonable cost to build a wagon road through it. A considerable part of the existing trails are so steep they are difficult to traverse with pack animals.

The summit of these mountains has the most extensive yellow-pine forest on the peninsula, but it is made up largely of medium-sized and small trees and scattered in many separate tracts difficult of access one from another. Two long ditches carry water from the western slope down to the Socorro and other placer mines in the foothill belt.

Sierra de Santa Ysabel and Sierra de Santa Maria.

As already noted, the San Pedro Martir Range ends at the mesa of Matomi, northwest of Point San Fermin. The next section of the main chain forms an offset and continuation of the main range to the north but is much nearer the coast. It is approximately 60 miles long

[1] Publications Field Columbian Museum, Zool. Series, III, p. 203, 1903.

and divided near the middle by El Tule Arroyo, which heads on the border of the tableland near the Onyx mine. The section of these mountains north of El Tule Arroyo is known as the Sierra de Santa Ysabel and that to the south, extending to Calamahue Arroyo, as the Sierra de Santa Maria. This range is mainly rather low and broken, especially in its southern part, where in places the crest of the peninsular divide is formed by the eastern border of the tableland, which drops away precipitously 1,000 feet or more on the east front, to the low basal plain of Santa Maria sloping to the gulf and dotted with hills and low ridges.

The Arroyo de Santa Maria, on which is located the ruins of the old mission of Santa Maria, cuts through the southern part of this range not far from the site of the old placer mining camp of San Francisquito. The ruins of this camp are on the coastal plain about 2 miles east of the high escarpment marking the front of the main range. Between the camp and the gulf are scattered low hills and ridges.

It is a well-formed and rather narrow range of abruptly rising, barren rocky ridges broken by peaks from 2,500 to over 3,000 feet high in its northern part and becoming higher near the southern end, where, southwest of the old Santa Maria Mission, a mountain which I have named Ugarte Peak, rises to about 4,753 feet. It is a typical barren rocky desert range with small streams in parts of El Tule and Santa Maria Canyons. Elsewhere water is extremely scarce and mainly limited to small tinajas.

The west front of the range forms a high abrupt wall, with serrated skyline, limiting the eastern border of the desert Llano de los Buenos Aires. The base of the eastern slope descends through low tablelands and hills to the shore of the gulf, where it ends mainly in low rocky bluffs. El Tule Canyon cuts entirely through the range, its upper end heading on the border of the Llano de Buenos Aires not far from Onyx, where onyx has been mined for some years and hauled to the Pacific coast. The eastern border of this interior plain and the low foothills bordering the western base of the range in this section are formed of nearly horizontal beds of limestone.

Northwesterly from San Francisquito the range breaks down and the eastern border of the tableland forms the top of the main divide. Immediately south of this pass in the range rises a small group of rounded mountains having an extreme altitude of about 3,500 feet. Through the southeastern border of this small range Calamahue Arroyo cuts its way. The extreme head of the arroyo extends through the range to the eastern border of that part of the main central plateau known as the Llano de Santa Ana, thus diverting to the gulf a little of the former drainage of the Pacific slope. The pass through the mountains at this point has an altitude of about 1,200 feet.

Sierra de Calamahue y San Luis.

Southeast of the extreme head of the Calamahue Arroyo rises the highest mountain in this section of the peninsula, Dos Picachos, with an altitude of about 5,440 feet. A few scattered trees were visible on the higher northern slope of this otherwise barren mountain. Dos Picachos forms a part of a high, abruptly rising, but round-topped, range which extends from the upper part of the Calamahue Arroyo east to the gulf and southeasterly parallel to and in a broad belt along the gulf coast to a point southeast of Yubay, where there is a break in the range opposite Remedios Bay. This range is mainly of granite and has a few outlying hills and ridges of the same material. It rises abruptly like a wall from the table-land along the eastern border of the Llano de Santa Ana. The Calamahue Mission was located near the lower end of Calamahue Canyon, close to the northwestern end of this mountain range. Throughout most of these mountains water is extremely scarce and the slope rocky and barren, but little vegetation being able to gain a foothold.

Sierra de Las Flores.

The Sierra de Las Flores extends from the north side of Los Angeles Bay to the south side of San Rafael Bay. It is a broken range bordering the coast in a generally northwest to southeast course. Throughout its length scattered peaks rise from 2,000 to nearly 4,000 feet. This range and the southeastern part of the Sierra de Calamahue follow the gulf coast much more

closely than the main chain farther north. Both ranges are excessively arid and barren in character. Many miles of their west front, overlooking the eastern border of the interior table-land, appear to be naked rock, in sharp contrast to the adjoining surface of the table-land with its abundant desert vegetation.

The Arroyo de Santa Ysabel has cut back through the main range and drains a small part of the eastern border of the central table-land into San Rafael Bay, thus making a low pass similar to that formed by Calamahue Arroyo.

Immediately south of San Rafael Bay the mountains are close to the coast and reach an altitude of a little over 1,000 feet. To the southward the main range gradually trends farther away from the coast and increases in height to culminate in Goldman Peak, about 5,000 feet in altitude, located close to 28° of north latitude, northeast of the old mission of Santa Gertrudis. Still nearer the mission lies Bryant Peak, with an altitude of nearly 4,500 feet. On the table-land west of this part of the main range are numerous scattered knobs, hills, and mountainous ridges, including the isolated group of small mountains in which the mining camps of Calmalli and Campo Aleman are located, with other low hills and ridges still farther west on this plain.

The Sierra Calmalli is a short, bare, and rocky group of desert mountains rising abruptly from the plain a few miles north of the small mining camp of Calmalli. From the Sierra Calmalli northwest to Yubay several abrupt, isolated mountains and small ranges are scattered over the table-land. These mountains are mainly of the pale gray granite of which most of the mountains are made from the northern border all the way down the main chain and on the adjoining part of the table-land to the west, as well as to the shore of the gulf on the east. This granite formation comes to an abrupt termination near Santa Gertrudis and is replaced by heavy beds of sandstone overlaid by great lava beds and other volcanic material, forming an elevated plateau extending thence southward to La Paz Bay.

MOUNTAINS OF THE GREAT VOLCANIC PLATEAU.

The great volcanic region of Lower California forms an elevated plateau, marked near its northern point, northeast of the old mission of Santa Gertrudis, by Goldman Peak (altitude, 5,000 feet), and extends thence southeasterly to the west side of La Paz Bay. The plateau covers most of the middle eastern parts of the peninsula within the limits named, including a distance of about 300 miles in length by from 20 to 30 miles in width. The basal or underlying formation of the plateau is composed of sandstone, upon which are superimposed the volcanic mountains, with lava beds of varying thickness covering practically all of its surface. The slope of the plateau descends westerly and southerly from near its eastern crest down to the border of the Vizcaino Desert and Magdalena Bay along the Pacific coast. A broad westerly extension of the plateau separates these two great coastal plains by a series of low foothills, ridges, and mesas. The surface of the plateau varies considerably in character and elevation from near sea level to above 3,500 feet altitude. Over much of its extent it is extremely rough and broken and for hundreds of square miles its surface is buried in masses of loose, shattered fragments of lava. The drainage of the plateau to the Pacific is mainly through deep, sharply cut canyons, in which are located some of the most fertile and populous oases of the peninsula, among which are San Ignacio, La Purisima, and Comondu, all three of which were the sites of missions established early in the history of the peninsula.

The mountains in this area are all volcanic in character and constitute a part of the main chain of the peninsula. They consist of small mountain ranges, mountain groups interspersed with ridges and isolated peaks, many of the latter being volcanic crater cones. Together these mountains constitute a ragged crest along the eastern side of the plateau. The eastern front of the plateau rises abruptly from near the gulf coast, or a short distance inland, to altitudes varying from a few hundred to more than 4,000 feet. Where there is an intervening basal plain it is more or less broken by foothills and low mountains. The principal mountain groups forming the main chain in this region, beginning at the northwest and extending southeasterly,

are the Sierra de San Francisco, Volcanes de las Tres Virgines, Sierra de Santa Lucia, Sierra de las Palmas, Sierra de Zacatecas, and Sierra de la Giganta.

The Sierra de San Francisco.

This range of volcanic peaks and craters, forming a section of the main chain, rises from the top of the plateau a little southeast of Santa Gertrudis, with Goldman and Bryant Peaks as its outlying northern summits. It is formed by a series of ridges, peaks, and craters, extending southerly to within a few miles of San Ignacio, where the range ends at the Cerro Colorado, and the slope descends to the low table-land pass which crosses the peninsula by way of San Ignacio and between the Tres Virgines and the northern end of the Sierra Santa Lucia. The Sierra de San Francisco as a range is wholly separated and distinct from the other groups of volcanic mountains known as the Volcanes de las Tres Virgines and the Sierra Santa Lucia, the volcanic activity forming these groups of mountains apparently occurring independently and at different periods.

The Sierra de San Francisco rises from the higher middle part of the northern section of the plateau, which is here from 15 to 20 miles wide, with an undulating surface reaching an altitude of at least 3,500 feet along the middle and eastern sides, above which rise the high elevations of the mountains. The eastern slope of the plateau presents a high, bold escarpment, the general appearance from the gulf being that of an abruptly rising range of mountains, of which the Sierra de San Francisco and outlying peaks for a certain distance form the summit.

The general surface of this section of the plateau is entirely covered with heavy beds of lava overlying the basal sandstone formation. Over large areas the lava is shattered into large angular fragments which render passage almost impassable, even to a man on foot. This section of the plateau is drained by a number of deep, rugged canyons rising high up near the eastern border and descending westerly to the border of the Vizcaino Desert. Practically all of the larger canyons have water somewhere along their course, but none carries a permanent running stream to the edge of the desert. The most important of these canyons is that of San Pablo, near the northern border of the plateau, in which, near its upper end, occurs a small permanent stream which sinks in the sand just below the point where was located the old mission of San Pablo. (See Pl. 9, Fig. 2.) A small amount of water occurs here and there in tinajas, in some of the other canyons, and in a few of them small streams flow down short distances high up toward their heads.

Further details concerning the character of the section of the plateau along the western side of the Sierra de San Francisco will be found in the narrative of our expedition.

Volcanes de Las Tres Virgines.

The Three Virgins are three high, black, volcanic crater peaks made up of black lava and other volcanic material. They rise boldly in an islandlike group 12 or 14 miles from the Gulf of California on the northern side of the lava plain which extends northeasterly as a low pass from the Vizcaino Desert by way of San Ignacio across the plateau to the gulf coast. The three peaks vary in altitude from about 4,400 to over 6,500 feet and form a strikingly conspicuous landmark when viewed from the gulf. These volcanoes were the most recently active of any on the peninsula, the last eruption reported having been in 1746. They are said to still send out vapor and gases from crevices near the summit and to contain deposits of sulphur.

Sierra de Santa Lucia and Sierra de las Palmas.

Southeasterly from the Tres Virgines and about 10 miles from the gulf shore rises abruptly the volcanic peak of Santa Lucia, with an altitude of about 3,000 feet. This volcanic cone forms the northern end of a range of continuous and closely set volcanic peaks extending in a southwesterly course toward the middle of the plateau and culminating in La Bandera Peak, with an altitude of 5,202 feet. Beyond this, near the middle of the plateau, rises a group of high cones and peaks, known as the Sierra de las Palmas and culminating in El Puro Año (5,828 feet), the highest volcanic peak south of the Tres Virgines. Southeasterly from this group of mountains occurs another group of volcanic peaks known locally as the Sierra del Valle.

The Sierra Santa Lucia is a sharply ridged, ragged range of mountains about 20 miles in length and of comparatively recent origin. It is formed by a series of sharp volcanic peaks and knife-blade ridges of bare lava almost wholly devoid of vegetation except on its lower slopes and in the bottoms of canyons. Its western slope descends sharply to the table-land plane which extends toward San Ignacio, and the sea slope is even more abrupt. The crest of the range where we crossed it south of Santa Lucia Peak is a thin ridge only a few yards wide. From the eastern base of these mountains to the shore of the gulf extends a low table-land forming an extension of the plateau through the pass which lies between the Tres Virgines and Santa Lucia Peak. This table-land gradually slopes easterly to end on the shore in long lines of cliffs and bluffs 75 to 200 feet high. It is drained by narrow, abruptly walled canyons.

Everywhere along our route through the Santa Lucia Mountains we passed over and among extended beds of black lava devoid of the slightest covering and some of them with the lava cooled in fantastic forms, with a surprisingly recent appearance. In other places the lava beds were shattered and broken. Water and vegetation were extremely scarce throughout these mountains, which were the most desolate and forbidding we saw during our expedition.

The great lava covered table-land on the west base of the Sierra Santa Lucia extends also along the entire west front of the Sierra de las Palmas and the Sierra Zacatecas, becoming gradually higher south of the Santa Lucia Range. The part of this table-land southerly from the Sierra Zacatecas sloping westward and southward is scored by deep canyons which end on the border of the Vizcaino Desert.

Near the mouth of Arroyo Pabellon the peninsula becomes narrow and its width is almost entirely occupied by the mountainous plateau, the lower western border of which approaches or quite touches the Pacific coast, thus forming the southeastern boundary of the Vizcaino Desert and the northern border of the Magdalena Plain.

The eastern front of the Sierra de las Palmas, which is practically continuous with the east front of the Sierra Santa Lucia, is more abrupt than the western slope and is separated from the gulf by the low Llano de San Bruno. Water as well as vegetation is extremely scarce throughout these mountains.

Sierra de Zacatecas.

This rough and broken group of volcanic mountains forms a broad belt along the west side of Concepcion Bay from near Mulege to the southern end of the bay and inland to include the Cerro de Zacatecas and Cerro Guajademi. It forms the southeastern end of a long crescent of volcanic ridges and peaks, beginning with Santa Lucia and extending in crescentic form, with the bow to the west, to Guajademi. The Sierra de Zacatecas rises abruptly on its eastern side and is extremely ragged and broken all along the crest, especially about the peaks of Zacatecas and Guajademi. To the west its flank rests on the plateau and is but little less abrupt and rugged.

The Arroyo del Potrero heads on the northern slope of Guajademi Peak and drains down through the little town of Mulege to Concepcion Bay, while the great canyon of the Arroyo de San Jose heads on the southern slope and immediately across a narrow pass from the extreme head of Potrero del Arroyo. The long peninsula forming the eastern side of Concepcion Bay is covered by an abruptly rising mountain ridge about 2,500 feet high, which descends to the sea on all sides except the south, where the range descends and ends on a low plain, giving it an isolated islandlike appearance.

Sierra de la Giganta.

Southeasterly from Concepcion Bay, a little north of 26° of latitude, the high eastern crest of the plateau is marked by a few peaks along its summit which parallel the gulf coast a few miles inland, while a series of detached ridges and peaks more closely border the gulf shore.

Twelve or fifteen miles northeast of Comondu rises the isolated Cerro de la Giganta, with an altitude of almost 5,800 feet. This peak on the middle western slope of the central plateau rises boldly as a huge rocky pinnacle, forming a notable landmark visible for a great distance along the western side of the peninsula. This mountain, with Encinos Peak located a little

farther to the northwest, forms the northwestern end of the Sierra de la Giganta, which extends as a broad mountain belt thence southeasterly to the gulf and follows the coast thence more or less closely to La Paz Bay. The range consists of a series of volcanic peaks and ridges superimposed on deep beds of sandstone. It is rather broader near the northern end and decreases southward until it becomes a narrow belt along the eastern border of the plateau.

The broadest and most impressive part of the great lava-covered plateau is located between San Ignacio and Comondu. It is an area of tremendous former volcanic activity. The underlying sandstone is heavily capped by great beds of lava and the surface of the undulating and broken plain is dotted with craters and over great areas is covered with beds of bare lava, sometimes in almost unbroken sheets and again in a sea of shattered fragments. Deep canyons cut their ragged way through this dark lava plain, in the two largest and most notable of which lie the oases of La Purisima and Comondu. (See Pl. 13, Fig. 2.) In these two canyons small streams flow for miles down their bottoms but elsewhere water is scarce. Vegetation is scanty on the top of the plateau but abundant in the bottoms of all the canyons.

Southeasterly from a line drawn east and west across the peninsula through the old mission of San Francisco Xavier to San Luis the plateau retains about an equal breadth, its abrupt and mountainous eastern border near the gulf coast, while its western border descends gradually to the eastern edge of the Magdalena Plain. Southeast of San Luis the plateau gradually narrows with the lessening width of the peninsula, and its surface is less and less broken with ridges and peaks, until on the west side of La Paz Bay it becomes a gently inclined table-land with a series of high cliffs along its eastern front bordering the bay and an undulating slope to the west. The surface of this slope is much broken by irregular lava beds and scored by canyons. The high cliff front of the plateau around the north and west sides of the bay is entirely of this sandstone worn into numberless picturesque contours and scored by several deep canyons.

The highest mountain in this range south of La Giganta is El Mechudo, at the southern end of the range, near the north end of La Paz Bay, with an altitude of about 5,000 feet. From near this point the range decreases in altitude southward and is soon lost in the high slope of the plateau, the entire surface of which descends gradually and merges into the pass extending across the peninsula at the head of La Paz Bay.

MOUNTAINS OF THE CAPE REGION SOUTH OF LA PAZ BAY.

As already noted, an arm of the Magdalena Plain crosses the peninsula to the head of La Paz Bay, thus forming a broad low pass completely separating the mountains of the northwest from those southeast of the bay. A line drawn east of south from La Paz to Todos Santos on the Pacific coast would mark the approximate southeastern limit of this plain. Thence to the east and southeast the southern end of the peninsula is mainly mountainous.

Compared with the main chain to the north the mountains south of La Paz Bay have their formation and positions relative to the coasts completely reversed. Thus the Sierra Victoria, which here forms the southernmost extension of the main peninsular chain, and like the San Pedro Martir Range is composed of pale gray granite, borders the Pacific coast from a few miles inland from Todos Santos to Cape San Lucas and presents its boldest and most precipitous slope to the west. The lower and more unimportant mountain groups in this section of the peninsula fill the interior and border the gulf coast.

Sierra de la Victoria.

The Sierra de la Victoria is the continuation of the main peninsular range south of La Paz Bay. It is high and narrow, rising boldly from a low base level, with many precipitous and rocky slopes to numerous sharp peaks in linear series varying from 5,000 to about 8,000 feet in altitude. Its rugged and precipitous character gives the range a notable individuality which impresses one from every point of view. At the northern end the range begins about 12 miles northeast of Todos Santos and extends a little east of south more than 50 miles to the extreme southern end of the peninsula near Cape San Lucas. On the west a belt of small plains, low-sloping mesas, and foothills from 8 to 12 miles broad separate it from the shore of the Pacific

south about to Mount Santa Genoveva. Thence to Cape San Lucas the western foothills become much higher and really form a broadening of the range and descend to form precipitous fronts along the shore of the Pacific. At the southern end of the peninsula the San Jose Valley separates the southern end of the Victoria Range from the mountains bordering the gulf coast. Farther north the Sierra Victoria is connected with the mountains of the gulf side by a lower ridge and series of rounded hills which form a divide at the head of San Jose Valley.

Both slopes of the Victoria Range are very abrupt, but the western is much more precipitous than the eastern side. The entire range is almost wholly granite, which on the west is almost bare rock from base to summit. The northern end of the range rises abruptly like a gigantic headland, overlooking the Magdalena Plain to the north and west. The extreme northwestern point of the range is formed by La Aguja (The Needle) Peak, a sharply pointed granite pinnacle with an altitude of 6,100 feet projecting like a buttressed spur from the main mountain mass. This peak presents a series of pale gray cliffs and precipitous rock slopes about 4,000 feet high, fronting the plain on the north and west, and is a conspicuous landmark from La Paz and other points on the plain. Similar high bare cliffs and slopes of gray granite extend around the north end and all along the west face of the range, resembling the most precipitous slopes on the east front of the San Pedro Martir Mountains. Mount Limantour, with an altitude of about 6,300 feet, forms the extreme northern end of the high part of the range, but foothill ridges extend a few miles farther. Mount Troyer, with an altitude of about 5,500 feet, is the southernmost high peak, and south of this the range becomes steadily lower through a series of hills and small ridges to the coast near Cape San Lucas. The cape itself is a small outlying granite ridge representing one of the terminations of the range.

Santa Genoveva, the highest peak, a bare sharp pinnacle close to the middle of the range, has been estimated by Dr. Eisen to reach an altitude of about 8,000 feet, but has not been accurately measured. The next highest peak is Mount Porfirio Diaz, a little over 7,000 feet high, near the northern end of the range. The remainder of the high peaks vary from about 5,000 to a little over 6,000 feet.

Both slopes of the range are scored by parallel series of deep ragged canyons heading high up near the crest and forming precipitously-walled gashes down the slope. These canyons have an easterly or westerly course, depending on the side of the range, and are separated by high sharp buttresslike ridges, leading from near the mountain tops down to the basal foothills. On the western side the slope of the main range is more abrupt and the main canyons shorter, but all extend down through the foothills to the sea and are separated by long, parallel foothill ridges, which in most instances also descend to the coast. On the east side the slope, while abrupt, is much less precipitous. From the northern half of the range deep canyons lead easterly through the foothills and bordering mountains to the gulf. The southern half of the range has a shorter slope on the east side than it has farther north and the main canyons on this side descend to the San Jose Valley. That outlying part of the southern section of the range known as the Sierra de San Lazaro is narrow and cut into high, rocky peaks and sharp ridges. There is no continuous crest throughout this part of the range, nor is there any extended moderately level area.

It may be noted by a glance at the map that the main canyons on the two sides of the entire range head almost opposite one another. In the southern half the erosion has cut through the crest and made deep passes with altitudes varying from 3,000 to 4,000 feet at the heads of the canyons, thus dividing the range into a series of high, sharply sloping ridges. These ridges have nearly parallel east and west courses at right angles to the axis of the range and culminate midway in high, bare granite peaks. In the middle of this range, owing to the precipitous slopes of the ridges, it is practically impossible to follow near the top in traveling north or south, but a detour must be made around the bases or middle parts of the separate ridges. The only comparatively level elevated area in this section is north of Mount Troyer and easterly from El Taste where Dr. Eisen found some small flats, one of which, on the banks of a small stream, contained about 30 acres. The drainage of all the east slope of the Sierra de San Lazaro is into San Jose Valley.

The northern part of the Sierra de la Victoria from and including the Cerro San Francisquito to Mount Limantour, and known locally as the Sierra de la Laguna, has a high and fairly continuous but extremely narrow crest. Here deep canyons head opposite one another on the east and west slopes, the same as along the range farther south, but the divides between the peaks are not deeply cut, so that the range has a generally higher appearance and is not so definitely separated into a series of long east and west ridges which extend across both slopes as in the Sierra San Lazaro. The largest elevated area in the entire range is at the northern end, where La Aguja, Mount Limantour, and Mount Porfirio Diaz form a triangular group 4 to 5 miles across, inclosing a small basinlike valley known as La Laguna. From the valley comes the name Sierra de la Laguna applied to this end of the range. The crest of the range south of La Laguna is extremely narrow, in places being barely wide enough to permit a foot trail along the crest, the slopes dropping down precipitously for several thousand feet into great canyons on the west. The west slope is too steep for trails, but the east slope is easier, although so steep that the few trails are difficult to ascend with saddle and pack animals. The ridges between the canyons are also narrower and sharper on the west side. The main canyons head close up against the crest on both slopes of this part of the range, and on the east side many steep subordinate ridges and spurs occur in the upper parts of the canyons, rendering travel extremely difficult. The east slope of the Sierra de la Laguna drains easterly through several nearly parallel canyons which unite in the foothills and lead through outlying hills and mountains to the gulf. A dividing ridge and series of low rolling hills north of Miraflores connect the east base of the Sierra de la Laguna with the mountains near the gulf shore.

La Laguna Valley is a small, flat-bottomed basin about a mile or more long in an easterly and westerly direction, and half a mile wide, located at an altitude of about 5,500 feet in the middle of the triangle formed by La Aguja, Mount Limantour, and Mount Porfirio Diaz at the north end of the Victoria Range. It is surrounded by steep slopes rising from 100 to 500 feet above it, the highest slopes being on the south and west. Several little streams flow out of gulches at the head of the valley and unite in a small channel down the middle of the flat. The bottom of the valley is said to have been formerly occupied by a shallow lake, from which the name is derived, but a flood cut down the lower end and drained it. The lake, if it ever existed, had long been dry when Belding visited it in 1882. The bottom of the valley has a scanty growth of herbage, but the surrounding hill slopes are overgrown with a low forest of pinyon pines and oaks, the only mountain forest in the peninsula south of the San Pedro Martir Mountains. It is a beautiful place and has an attractive camping ground by the ruins of some old cabins at the upper end where a potato ranch was established long ago, when the mines at Triunfo were in active operation.

The Sierra de la Victoria has the greatest precipitation of any section in the southern end of the peninsula and is the source of practically all of the surface and underground waters in the region south of La Paz Bay. La Laguna has been visited by numerous naturalists and is the type locality for a number of species of birds and mammals.

Sierra de la Trinidad.

East of the San Jose Valley the Sierra de la Trinidad rises abruptly as a low, barren mountain group, the highest peak of which reaches an altitude of a little more than 2,800 feet. The group is made up of some flat-topped and some pointed elevations, forming a compact oval mountain mass bordered on the south and east by the gulf, on the west by San Jose Valley, and on the north in part by the gulf and in part by a series of low hills near Santiago, which form a broad and comparatively low area between it and San Bartolo and other higher mountains to the north. These mountains are said to be of limestone formation. We did not visit them.

From San Bartolo Peak northwesterly to the point forming the east side of La Paz Bay extends a short range apparently without any general name but of rugged and broken formation so rocky and barren that at a distance it appears to be without vegetation. Along the line of these mountains is a series of peaks from 3,000 to over 4,600 feet high nearly paralleling the gulf coast and beginning with San Bartolo on the southeast and ending with the Cacachilas Peaks a

few miles southeast of La Paz. This group consists of four sharp, extremely barren and rocky peaks, varying from about 3,500 to a little over 4,200 feet in altitude. These mountains are on the border of the Magdalena Plain surrounding La Paz and are the mountains nearest that place. From the Cacachilas northwesterly the range descends rapidly to a low rocky and hilly ridge forming the point of the narrow cape east of La Paz Bay. This short and broken range presents its most abrupt and rugged front to the gulf coast, where its slopes sometimes rise directly from the sea or are separated from the shore by a narrow belt of sandy lowland. The gulf coast from near San Jose to the entrance of La Paz Bay is mainly bold and rocky in character. Dr. Eisen reports that the mountains northwesterly from San Bartolo Peak are mainly of stratified red volcanic rock.

From Santiago north to San Antonio Peak the gulf coast hills and mountains are connected with the Sierra de la Laguna by low foothills and intervening ridges, but the two ranges form distinct mountain groups of different geological structure. Northerly from San Antonio Peak the westerly front of this part of the gulf coast range, of which the Cacachilas form a part, faces the end of the broad Magdalena Plain.

COASTAL MOUNTAINS OF THE PACIFIC SIDE.

As previously stated, the only definite coastal mountain ranges on the Pacific side of the peninsula are in detached sections separated by coastal plains of varying extent. Beginning in the north the first of these extends from near the international border to the northern end of the Plain of San Quintin. Next follows the section reaching from near El Rosario to Santa Rosalia Bay, and last the Vizcaino Range southwest of the Vizcaino Desert. The hills and low mountains between San Ignacio Lagoon and San Jorge Landing are an extension of the interior plateau and can not be considered as belonging to distinctively coastal mountain groups. The mountains along the Pacific coast southeast of Todos Santos to Cape San Lucas also belong to the main central system. The hills and ridges between the Vizcaino Desert and the Magdalena Plain are the lower border of the table-land; the mountains of Magdalena and Margarita Islands are islandlike isolated groups and the mountains along shore near the southern end of the peninsula belong to the main range of the interior. The three distinctly coastal ranges named above average from 1,000 to 2,500 feet in altitude and reach their greatest elevation of nearly 4,500 feet inland from Ensenada. North from San Ignacio Lagoon the coastal mountains of the Pacific side are immediately bordering or within a few miles of the shore and occupy the lower slopes of the great interior table-land. From near the California boundary south to Cape Colnett they form a rocky front, sometimes rising precipitously several hundred feet, broken here and there by small bays and the mouths of canyons coming down from the interior; similar conditions prevail alongshore from Rosario to Santa Rosalia Bay.

The coastal mountains rise abruptly on the lower slopes of the central plateau and are usually higher than most of that part of the plateau lying between them and the base of the main chain to the east, thus inclosing interior plains and valleys. Scattered among the coastal mountains are hills and mountains with flat-topped summits, forming mesas or table mountains reaching an extreme elevation of about 2,500 feet and a length of about 15 miles and breadth of 6 or 8 miles on the great San Carlos Mesa north of Santa Catarina Landing. Other notable mesas are Table Mountain, not far from the northern border; the high mesa near Cape Colnett; the broad-topped area just mentioned north of Santa Catarina Landing; and others north of Playa Maria Bay and in the Vizcaino Range. It has been stated that these high islandlike table mountains, with abruptly walled sides towering above and overlooking the present plateau, are the remains of a great elevated table-land which once covered all the peninsula but has been eroded to the present level, except for these remaining evidences. The fact that the many drainage ways from the present interior plateau lead down great canyons to the sea through the higher walls of the coastal ranges indicate that these channels were formed when the surface level of the interior was much higher than at present.

More details concerning the western coastal ranges of the peninsula are given farther on.

The Northwestern Coastal Ranges.

At the northern border and for a few miles southward the table-land bordering the west side of the main interior range descends to the Pacific coast. Beyond this to the southward, in a belt some miles in width along the coast, rises a series of hills and low mountains, the most notable at the northern end being Table Mountain (2,275 feet), inland from Descanso Point. The coastal mountains gradually increase in altitude to the southward and the rocky front alongshore becomes bolder. Gradually on the inland side of the range, northeast of the old mission of Guadalupe, a definite mountain crest is formed which extends for more than 75 miles in a southerly course, passing east of Todos Santos Bay and losing its identity south of the San Telmo Arroyo. On this ridge rise the highest elevations in the northwestern coastal range, including Three Peaks (4,432 feet), northeast of Guadalupe, and Las Animas Peak (about 4,900 feet) northeasterly from Santo Tomas. From the Salado River the main part of the coast range, as a broken continuation of the granite ridge just described, trends gradually more easterly away from the coast and merges into the high, broken, outlying spur of the San Pedro Martir Mountains northeast of San Quintin Bay. South of Trinidad Valley the base of the San Pedro Martir Mountains and the coast range are connected by series of low foothills and ridges until the coast range loses its identity as described above.

The eastern slope of the coast range is short and forms the western boundary of the interior plateau on which is located a series of small elevated plains and valleys, notably the San Rafael Valley, Alamo Plain, and Trinidad Valley, which lie between the coast mountains and the west base of the Sierra Juarez. The western slope is much longer and characterized by descending foothills and low mountains, which reach the shore and form a rocky coast line almost continuously from near the California border to near Cape Colnett.

South of Ensenada, as the main coast range trends farther inland, its western slope has a broadening belt of foothills and ridges, including several small basal valleys, to the west of which, parallel to the coast, is a rugged but lower range with a few peaks reaching an altitude of 2,000 feet or more. This secondary range closely borders the coast from Punta Banda on the south side of Ensenada Bay to within 8 miles of Cape Colnett, where the mountains descend to a plateau several hundred feet high which extends to the cape. Near here the coastal plain of Hamalu comes in, followed to the south by the Plain of San Quintin, the base of the mountains lying back from the coast except for a few low, narrow spurs extending to the coast between the plains.

The southeastern end of the coast range, northeast from San Quintin, merges into a high and broken mountain group forming a western spur of the San Pedro Martir Mountains, including two series of rounded ridges reaching extreme altitudes of nearly 4,000 feet. This mountain group is 12 to 15 miles broad and on the west sends down long plateaulike slopes to the eastern border of the San Quintin Plain. To the south slopes of these mountains merge directly into the great central plateau which descends from the southern end of the San Pedro Martir Mountains to the Pacific coast south of San Quintin.

Along the coast for a short distance north and south of San Quintin Bay, including San Martin Island, is an isolated volcanic area of lava beds with low crater peaks and volcanic hills. The Five Peaks are small, sharp crater cones which from the sea are notable landmarks for San Quintin Bay.

The northwestern coast range has the benefit of many fogs and fairly regular winter rains, hence water is more abundant in springs and small streams in the canyons of the west slope than elsewhere in Lower California. In addition to their own sources of water supply, the drainage from all the west slope of the high Sierra Juarez and San Pedro Martir Mountains is carried through canyons traversing the coast range. These canyons form deep rocky gorges, especially south of Ensenada, and carry more water than exists in any other area of the same size in the peninsula.

The slopes of the mountains facing the sea from Cape Colnett northward are generally devoid of trees and shrubs, but are green with grass and other small vegetation in winter. On slopes sheltered from the northwest sea winds and on sides of canyons back from the sea there

are scattered areas of live oaks and an abundant growth of shrubs. On the high seaward slope of the mountain immediately northwest of Ensenada a small area of California juniper forest occurs.

A wagon road leads from San Diego southward along the coast range to Ensenada and thence down the coast by San Quintin to beyond El Rosario; another leads from Ensenada back through a canyon in the range to San Rafael Valley, and other interior points, and across to San Felipe Bay, on the gulf. Several little valleys located between the higher parts of the coast range and the sea support small farming communities. Notable among these are the valleys at Ensenada and at Santo Tomas, the latter the site of one of the old missions.

From the southern end of the plain of San Quintin south to a short distance beyond Rosario the interior plateau descends directly to the coast through a series of gently rolling hills and ridges which form an abrupt and rocky coast line. Beyond this to the border of the Vizcaino Desert, beyond Santa Rosalia Bay, a broken coastal range almost everywhere shuts off the plateau from the sea. These coastal mountains are made up of irregular and broken ranges of hills, mountain peaks, and ridges. The most notable of these is the Mesa de San Carlos, a broad table-topped mountain a short distance from, and parallel to, the coast between San Carlos and Santa Catarina Landing. This great table-topped mountain rises to an altitude of from 2,000 to 2,500 feet, the summit being about 15 miles long in a northwesterly and southeasterly direction by 6 miles broad. Beyond this the next most important section is the Sierra Columbia, which parallels the coast on the western and southwestern side of San Andres Valley. This is a sharp-ridged range rising abruptly from the plateau to an altitude of about 2,500 feet. In many places groups of low hills border the shore line, scattered higher peaks rising to varying altitudes from 1,000 to about 2,500 feet. From the shore of Santa Rosalia Bay the coastal mountains extend southeasterly, coming to an end on the interior plateau nearly midway between Santo Domingo and Calmalli. The shore line from a few miles north of Santo Domingo is occupied by a coastal plain forming the northern point of the Vizcaino Desert. The coastal mountains between El Rosario and the end of the range on the plateau near Calmalli are extremely rugged and barren and almost without surface water with the exception of a limited number of tinajas. Underground water occurs at a shallow depth in a number of the larger canyons or drainage ways.

Vizcaino Range.

The small mountain groups known as the Sierra Santa Clara and Sierra Pintada form a single low range about 100 miles long, which Mr. Waldemar Lindgren has named the Vizcaino Mountains.[1] The range begins near Cape San Eugenio and extends southeasterly to near the head of Ballenas Bay, throughout its course lying parallel to the coast and a few miles inland on the southwest side of the Vizcaino Desert. The broad low desert on one side and the sea on the other isolates these mountains and gives them, when viewed from a distance, an island-like appearance. The relative situation, general appearance, and trend of the mountains on Cedros Island make it evident that they were once a part of the Vizcaino Range, as has been suggested by Mr. Lindgren.

The Vizcaino Range is mainly volcanic and is separated into two small groups by an open pass bordered by flat-topped ridges. The Sierra Santa Clara, at the southeastern end of the range, is a short compact group of ragged volcanic peaks 2,000 to 3,600 feet high with basal lava beds. The Sierra Pintada is a longer and narrower group with the higher peaks near the middle and having about the same altitude as the Santa Clara group. The range rises abruptly from the Vizcaino Desert on the east and has a gentler slope on the Pacific side, where it descends to the coast through a series of spurs and foothills. The Sierra Pintada is less rugged and broken than the Sierra Santa Clara and much of the southeastern part of its crest and flanking hills are table-topped. The Vizcaino Range is extremely barren, almost the only water being in a few hidden "tinajas" and still rarer small springs. Elephant wood and a few other desert species form the principal part of the scanty vegetation.

[1] Proc. Calif. Acad. Sci., III, 3d ser., pp. 25–33, 1890.

Dr. Eisen states that fogs and high winds are common in these mountains. This author also adds (what is apparent to anyone having a general view of this district) that when the Vizcaino Desert was submerged by the sea the Sierra Santa Clara and Sierra Pintada formed part of a long group of islands of which Cedros, Natividad, and San Benito are the existing representatives.[1]

In 1893 and later placer gold was mined by dry washing on the western slopes of the Sierra Pintada; water was found in a number of wells near which was located the mining camp of San Andres, a few miles from San Roque Landing. The mines were completely abandoned years ago and this part of the peninsula has since remained without permanent occupation, but has been visited by occasional prospectors and other wanderers. The commonly used trail to these placer mines is from San Ignacio, by way of San Angel, and thence across the desert through the pass between the Sierra Santa Clara and Sierra Pintada.

COASTAL AND OTHER MOUNTAINS OF THE NORTHEAST.

A low, sloping plain with scattered desert mountain ranges covers all of the northeastern part of Lower California between the abruptly rising east base of the Sierra Juarez and Sierra San Pedro Martir to the lower Colorado River and shore of the Gulf of California, and extending from the northern border south to near Cape San Fermin. This plain is one of the hottest and most arid districts in all Lower California and forms the southern extension of the Colorado Desert. The surface of the plain is interrupted by five short, narrow ranges, four of which form a broken coastal chain extending in an irregular, sinuous line from the California border southeastward approximately parallel to the course of the Colorado and of the shore of the gulf. One of the ranges, the Sierra de la Tinaja, is a spur from the Sierra Juarez extending northeasterly into the plain. The four ranges forming the distinctively coastal chain are the Sierra Cocopah, Sierra Pinta, Sierra San Felipe, and Sierra Santa Rosa. All are typical barren desert mountains rising abruptly from the surrounding plain and having very little surface water, mainly in a few tinajas, or natural rock tanks, in the bottoms of canyons. On the east side of the Sierra de la Tinaja are the Arroyo El Tule and Arroyo Grande, which rise on the eastern base of the Sierra Colorado, and have surface streams of clear water for several miles down their courses, the largest being in the Arroyo Grande.

The Cocopah and Pinta Ranges are surrounded by a low desert plain but little above sea level. The Sierra San Felipe and Sierra Santa Rosa have their eastern bases on plains but little above sea level, but on the western side the basal plain is in places 1,200 feet above the sea. As a whole, these small ranges, like the main chain, have a shorter and more abrupt eastern slope and a more gradual western one. They do not appear to be connected with any definite mountain range north of the border and toward the south are cut out by the main peninsular chain, which approaches the coast opposite Cape San Fermin. These ranges vary from 500 feet to nearly 4,700 feet in altitude.

Sierra Cocopah.

This range lies near the northern border of the peninsula immediately west of the lower Colorado River and extending in a northwesterly to southeasterly course rises islandlike from a sandy plain only a little above sea level. Owing to this low base level with its high rocky slope the Cocopahs are an unusually striking group of mountains, the southern part of the range rising to an altitude of more than 3,100 feet. (See Pl. 20, Fig. 2.) Signal Mountain, with an altitude of 2,400 feet, rises as an isolated peak on the plains near the California border as an outlying point of the range. The main group of these mountains begins in a peak about 1,000 feet high southwest of Mexicali and a high, narrow, serrated range extends thence southeasterly about 50 miles to a point near the head of tidewater not far from the mouth of the Colorado River. The Cocopahs are of much-eroded gray granite with the narrow backbone marked by a series of sharp peaks. In the period when the Gulf of California extended north over the Imperial Valley to the Salton Sea the Cocopah Range was unquestionably a great rocky island. At the

[1] Bull. Amer. Geog. Soc., XXXII, p. 420, 1900.

west base of this range there still remains a depression below sea level containing a saline lagoon known as Laguna Maquata or Laguna Salada, which at times of exceptionally high water receives drainage from the Hardy River through a low pass at the southern end of the Cocopahs.

A low volcanic peak, called Cerro Prieto, is located a short distance from the east base of the Cocopahs near the northwestern border of Volcano Lake. The flood plain of the Colorado, which is almost wholly overflowed during seasons of high water, extends to the eastern base along the southern part of the Cocopahs. At present the main channel of the Colorado flows through Volcano Lake and the Hardy River along the eastern flank of these mountains. Water occurs in a few tanks on both slopes of the Cocopahs, and Palm Spring, the only living water in the range, is found on the middle of the west base. The range is extremely rocky and barren of plant life.

Sierra Pinta.

The Pinta Mountains, about 20 miles in length, lie directly west of the extreme head of the Gulf of California, with almost as low a base level as that of the Cocopahs. They are separated from the Cocopahs by a low gap more than 10 miles in width through which at times of flood water flows into the Laguna Maquata. These mountains are mainly volcanic in character, have a northeasterly to southwesterly direction, with their southern end separated by a low, narrow pass from the northern end of the Sierra San Felipe. They are lowest near the northern end and rise to an altitude of about 2,200 feet in the south. Three low passes cut the range in the north. The range is formed mainly of a reddish volcanic rock, to which it owes its name. The only water in the range is that in a few small rock tanks or tinajas. To the west of the southern end lies the Arroyo Grande, in which a stream of water flows down from the main mountains of the interior, and the well-known water hole, Tres Pozos, which has been a favorite camp for many hunting parties in that region, lies on the desert to the west of its northern end.

Along the coastal plain from the southeastern side of this range extends a series of scattered hills to the vicinity of San Felipe Bay. Between these hills and the coast the plain is but little above sea level, but rises gradually toward the interior.

Sierra San Felipe.

This range begins opposite the southwestern end of the Sierra Pinta and extends about 30 miles in a southeasterly direction to the low Buena Vista pass, separating it from the northern end of the Sierra Santa Rosa. The range forms a high, narrow ridge of granite broken by several rounded peaks and scored by canyons along its flanks. Its northern end rises abruptly to the highest altitude of the range, about 4,600 feet, on Cerro Borrego. The Sierra San Felipe extends nearly parallel to and about 12 to 18 miles east of the north end of the San Pedro Martir Mountains, from which it is separated by the San Felipe Valley. The northern end of the range is about 18 miles inland from the gulf, but its easterly trend brings the southern end to within about 10 miles of the shore. As already noted, the coastal plain between these mountains and the gulf is dotted with outlying scattered hills. Water in tinajas is extremely scarce, and the rocky slopes are very barren of vegetation.

From the high crest of the San Pedro Martir Mountains we had a fine view over the top of the Sierra San Felipe, and it was evident that some of the outlying spurs and ridges as well as the northern end of the main ridge are excellent illustrations of "buried" mountains. The granite of all the ranges in this region is easily weathered and extremely friable. The resulting fine sand and gravel has been washed down the mountain side in such enormous quantities that gradual and continuous slopes extend up their bases. In the present range a continuous slope extends from the bottom of San Felipe Valley, on the west side, up to the extreme head of some of the large canyons, the slope broadening at the canyon mouths thus appearing like huge deltas. The base of the mountains between these deltas is much lower than at the canyons. Where the mountain crest becomes lower, near its northerly end, some of the more scattered peaks become more and more buried until a number of them appear as a series of small, isolated, rocky points rising in a linear series, like little islands on the high, smoothly rounded ridge formed of the disintegrated sandy material into which the mountain has degenerated, and which forms an

unbroken slope from the summits of these rounded ridges to the bottoms of the adjacent valley or plain.

Sierra Santa Rosa.

This is the southermost part of the irregular chain of desert mountains beginning with the Cocopahs on the north and forming the coastal range in the northeastern part of the peninsula. It is a narrow granite range with rounded summits beginning a few miles inland from San Felipe Bay on the south side of Buena Vista Pass and extending southeasterly parallel to the coast for about 45 miles to the vicinity of Point San Fermin. The highest elevation of the range is Cerro Kino, directly west of San Felipe Bay, near the northerly end of the range, with an altitude of 4,280 feet. From this point southward the range gradually decreases in elevation. The western side of the range faces the San Pedro Martir Mountains across the desert San Felipe Valley. Like the Sierra San Felipe, these mountains are almost without water, even in tinajas.

THE PLAINS AND LARGER VALLEYS.

Although Lower California is mainly mountainous and hilly, numerous plains and valleys occur within its borders, some of them covering large areas. As described in the general notes on physiography, a long interior plateau begins at the northern border on the west base of the main mountain chain and is practically continuous along the western or southwestern side of this chain to its end at the low pass extending across the peninsula at La Paz Bay.

This plateau slopes in a westerly and southwesterly course toward the Pacific. Along its higher parts in the middle of the peninsula, near the base of the main chain, which forms their eastern border, extend a scattered series of small, open plains and valleys from near the California border to the border of the Vizcaino Desert, near Calmalli. Some of the more notable of these open areas, on the more or less hilly and broken plateau slopes, are as follows, beginning near the California border: Las Palmas and San Rafael Valleys, Alamo Plain, Trinidad Valley, Plains of Buenos Aires, Santa Ana, El Principio and San Pedro, and the deserts, or plains of San Julian, of Santa Maria, and the north end of the Vizcaino Desert. Many smaller valleys and shallow basins occur in the intervals between those named.

The most extensive plains of the peninsula border the Pacific coast. On the eastern or gulf side some small coastal plains occur, only a few of which are worth special mention, except the most important of all in Lower California, which is that at the southern end of the Colorado Desert, in the delta region of the Colorado River.

A brief account of the physical character of the main plains and valleys which we traversed or of which I have secured definite information is given below. Further details concerning these areas along our route are given in the narrative. The descriptions of the plains and valleys are arranged in their sequence, beginning at the northernmost coastal plain on the Pacific side and following around the coast to the head of the gulf. The interior plains and valleys are then mentioned in their sequence from north to south. All of the larger areas are included in the following list, but there are other small plains and valleys here and there which are not mentioned. Some of these contain little fertile oases which are occupied by small agricultural communities, but are of slight importance. The coastal plains contain nearly all of the comparatively level parts of the peninsula and in them are most of the lands available in bodies of any importance for agricultural development except that of the most limited and primitive kind.

Llano de Hamalu.

The Llano de Hamalu is a nearly level coast plain bordering the Pacific for about 30 miles from near San Telmo to Santo Domingo and limited abruptly, a few miles inland, by the outlying foothills of the interior mountains. For a few miles immediately south of Santo Domingo a series of low hills separates this plain from the northern end of the Plain of San Quintin. The channel of the Rio San Telmo extends to the sea along the northern border of this plain. It is mainly dry except during rains, but a small permanent surface stream flows through it in the lower foothills and along the upper border of the plain. Here a scattered group of small ranches forms the village of San Telmo. Several small ranches are cultivated on the southern

border of the plain along the Rio Santo Domingo, below the ruins of the old mission of the same name. Of these the ranch of an American named Young is locally noted for the variety of fruits grown successfully, including oranges, lemons, grapes, pears, apples, peaches, figs, and others. The wagon road from San Quintin to Ensenada crosses this plain.

Plain of San Quintin.

An extensive coast plain lies about San Quintin Bay extending from within a few miles of Santo Domingo, more than 20 miles northward of the port of San Quintin, to beyond Socorro 18 miles southward of the same place. The Llano de Hamalu might really be considered the northern end of this plain, the barrier between the two being series of low hills. The San Quintin Plain is nearly level or slightly undulating. Near the village of San Quintin it is 5 to 6 miles broad and narrows gradually to the north and south as the foothills, which limit the plain along its eastern border, approach the coast. The plain is open and more or less sandy in parts, especially south of the San Simon River, where a belt of sand dunes border the coast. Several canyons containing small permanent streams open on it along the foothills and the broad dry wash of San Simon River crosses it to the sea a few miles south of San Quintin. No permanent fresh water exists on the surface of the plain except the pools at Socorro, near the southern end, but considerable areas are underlaid by good water so near the surface that fruit and other trees may be successfully grown in places, as shown by the fig orchard and eucalyptus trees on the Santa Maria ranch, just south of the San Simon River and about 4 miles back from the coast. Marshy flats occur along the coast about San Quintin Bay, at the mouth of San Simon River, and at Socorro. The vegetation is so low and insignificant that the plain has the appearance of an open prairie. Extensive but unsuccessful efforts were made some years ago, by a company holding one of the large land concessions recently cancelled, to establish a large agricultural colony on this plain. A considerable area of good land exists and by proper management much of it could no doubt be reclaimed.

The Vizcaino Desert.

A broad and largely sandy plain, which may be called the Vizcaino Desert, begins on the Pacific coast a little south of Santa Rosalia Bay and extends southeasterly about 150 miles to a point on the coast southeast of Ballenas Bay. On the northern and eastern sides it is limited by the foothills and lower slopes of the great interior plateau. This plain is broadest opposite Scammon Lagoon, where it reaches a width of about 60 miles, and narrows to a point at both ends. It is the largest comparatively level area in the peninsula and is excessively arid throughout its extent. The northern section, from Black Warrior Lagoon to Santa Rosalia Bay and thence inland to beyond Calmalli, may be termed the Llanos del Perdido. Near the sea it is mainly flat and sandy, but the shore a few miles north of Santo Domingo Landing is bordered by a belt of high sand dunes replaced inland by a low clay flat, which soon merges into the gradually rising sandy plateau. South of Santa Rosalia Bay the coastal plain begins as a point, but broadens southward as the low hills along the coast gradually swing back into the interior and break into scattered groups, leaving a broad open expanse of desert bordering the shore as far as one can see to the southward. Inland about 3 miles across low sand dunes to the eastward of Santo Domingo Landing the surface of the plain rises abruptly with a steep escarpment about 50 feet high. Beyond this a sandy plain gradually rises to the eastward about 26 miles to a second escarpment of the same height, and thence on to the distant bases of the high mountains paralleling the gulf shore. From the first escarpment inland to Calmalli the plain is a part of the great interior plateau and rises gradually to an altitude of about 1,200 feet at Calmalli, but its general level is from 250 to 800 feet above the sea. A considerable number of small, islandlike barren hills and low mountainous ridges are scattered here and there over the plain, mainly on its northern and eastern parts. Among these is the group of low mountains in which the small mining camps of Calmalli and Campo Aleman are located.

The main part of the Vizcaino Desert lies south of the mesa plains of Santo Domingo. It averages lower than these mesas, the general level being from 75 to 300 feet above the sea, and is but little broken by hills or other marked elevations. Its broadest part extends as a gently

rising undulating plain from the seacoast, near Scammon Lagoon, about 60 miles inland to the base of the main mountain range on the east side of the peninsula, not far from the Mission of Santa Gertrudis, where the granite formation reaches its southern termination against great lava-capped mesas. Southward from this the desert is limited on the east by the lower border of lava slopes descending from the interior plateau and on the west by the Sierra Pintada and Sierra Santa Clara, which shut it off from the Pacific coast between Cape San Eugenio and Ballenas Bay. The desert narrows southeasterly between the coast and interior plateau to the vicinity of Ballenas Bay, whence it again becomes a coastal plain gradually narrowing to a point southeasterly, where the foothills of the interior plateau reach the shore 40 or 50 miles below Ballenas Bay.

The Vizcaino Desert is largely sandy and throughout its extent surface water is exceedingly scanty and widely spaced, the Ojo de Liebre (see Pl. 12, Fig. 1) and San Angel (see Pl. 11, Fig. 2) being about the only fresh water on it south of the well at Santo Domingo. Extensive salt deposits exist on flats near the heads of Scammon Lagoon and Ballenas Bay.

The northern part of the desert, over nearly all of the Llano del Perdido is covered with a remarkable growth of desert vegetation. Farther south between the coast and interior mountain ranges the vegetation is much smaller and sparser. Much of the land on the Vizcaino Desert is very fertile and with the application of water for irrigation would produce abundant crops. Unfortunately the scarcity of rain throughout this region and consequent lack of surface water, and the absence of underground water at a moderate depth except in certain limited areas, appear to bar forever any considerable agricultural development. About 12 miles inland from Santo Domingo Landing the sandy plain, overgrown with large and abundant desert vegetation, gives way to an open clayey prairie 4 or 5 miles in diameter and nearly bare of vegetation, known locally as the Llano de Berrendo. The plain about Ojo de Liebre, at the head of Scammon Lagoon, is also known as the Llano de Berrendo. Ojo de Liebre means Jack Rabbit Spring and not Jack Rabbit's Eye as has been stated by a recent author. Further details concerning parts of this desert are given in the accompanying narrative.

The Magdalena Plain.

The Magdalena Plain lies along the mainland shore of Magdalena Bay and thence up and down the coast. Next to the Vizcaino Desert it covers the largest body of nearly level land in the peninsula. It begins as a narrow point on the coast a little above the mouth of La Purisima Arroyo and gradually broadens southerly and southeasterly a distance of over 200 miles along the coast to within a few miles of the town of Todos Santos and near the base of the northerly foothills of the Victoria Mountains. Throughout most of its length this plain is almost entirely free from hills and rises gradually from the coast eastward a distance of 10 to 20 miles to the western border of the foothills of the interior plateau which extends down the middle of the peninsula. A few miles north of latitude 24° N. the main mountain chain and interior plateau end and the Magdalena Plain spreads easterly entirely across the peninsula to the head of La Paz Bay, thus forming a broad, low pass separating the mountains of the north from those of the cape district south and southeast of La Paz. Most of this plain is without permanent surface water except at considerable intervals, mainly in the bottoms of washes or creek beds extending out from canyons in the foothills. It is crossed by many large dry washes, and in many places underground water exists in considerable abundance not far below the surface. Artesian water was struck in one well below La Purisima some years before our journey and was reported to be still flowing steadily. The Magdalena Plain is fertile and mostly covered with a large and abundant growth of desert vegetation.

Immediately inland from the shore of Magdalena Bay is a shallow, nearly level sink about 20 miles long in an easterly and westerly direction, which becomes flooded in times of heavy rain. It is known locally as the Llano de Yrais and is mainly free from the heavy growth of desert vegetation common to the surrounding plain, thus giving it an open, prairielike appearance. This part of the Magdalena Plain was once the scene of an extensive effort by an American company, largely made up of men notable in American business and political life, to establish an agricultural colony. In 1870–71 500 American colonists are said to have been landed

here, but the experiment was foredoomed to the prompt and complete failure which overtook it. This plain except the southeastern end is nearly all within the lines of the grant owned by the Chartered Co. of Lower California. At Soledad or Matancita, the headquarters cattle ranch of this company, the manager had an irrigating pump installed and was successfully growing many fruits and vegetables. It was along the coastal border of this plain that the orchilla industry flourished some years ago.

San Jose Valley.

The valley of San Jose has an east of south direction for about 30 miles, beginning at an altitude of about 800 feet near the village of Miraflores and extending to the sea at the southern end of the peninsula, a mile below the town of San Jose del Cabo. The Rio San Jose flows down the bottom of the valley, which is a broad flat varying from a mile in width near San Jose to 3 or 4 miles near Santa Anita. It is bounded on the east by a range of barren round-topped foothills and on the west by the precipitous slopes of the San Lazaro Mountains, in the midst of which the sharp San Lazaro Peak rises as a bold landmark. Santa Anita ranch lies in a baylike western extension of the valley about 9 miles northerly from San Jose. From Santa Anita to Miraflores the west side of the valley is occupied by a rolling mesa, mainly of conglomerate, which rises abruptly in the form of a bench 50 to 100 feet above the general level of the rest of the valley and extends westerly to the base of the bordering mountains. The valley narrows between low rolling hills at the town of San Jose and then broadens to a small coastal plain 2 or 3 miles broad and extending about a mile inland. A fresh-water lagoon is formed by the San Jose River just inside the sandy beach at its mouth. At the time of our visit this was the most prosperous agricultural valley in the peninsula and maintained the town of San Jose del Cabo, containing about 1,600 inhabitants.

Plain of Ventanas Bay.

A narrow coastal belt of sandy plain, backed by abruptly rising mountains, occurs along the shore of Ventanas Bay, opposite Ceralvo Island, where an unsuccessful attempt to establish a colony is reported to have been made by an American company previous to 1865.

La Paz Plain.

As already mentioned, the southerly end of the Magdalena Plain extends entirely across the peninsula to the shores of La Paz Bay. Good water exists close to the surface all about the head of this bay, as evidenced by wells and by the luxuriant growth of palms and other vegetation irrigated from this source at La Paz. The plain rises gradually to the east and south toward the bases of the Cacachilas and other mountains a few miles away and to the south and southwest merges into the Magdalena Plain.

Plain of Loreto.

A fertile plain without surface water, but with an underground supply, extends 15 or 20 miles along the gulf near Loreto. Other small plains somewhat similar in character are said to exist on the coast and inland along the trail leading to the extreme head of Concepcion Bay. We did not traverse these plains, so can give no details concerning them.

Llano de San Bruno.

A coastal plain overgrown with desert vegetation extends for about 25 miles along the shore of the gulf from near Mulege north to the fishing villages of San Bruno and San Lucas, and thence inland 6 to 10 miles to the eastern base of the Santa Lucia Mountains. It has been called the Magdalena Plain, but in order to avoid confusing it with the plain of the same name on the west coast, the name used above is preferable. The plain rises gently inland and has some low barren hills scattered here and there around its borders, especially along its southern border near Mulege. The ruins of the old mission of Guadalupe are located at the edge of the foothills on its western side. Scattered over the plain are a number of deserted ranches where attempts have been made to cultivate the land. Water is plentiful a short distance below the surface, and some was being pumped, but primitive methods of raising it for irrigation are impracticable. As long ago as 1866 some of the land on this plain had been acquired by a San

Francisco company for colonizing purposes, but nothing was accomplished. At the time of our visit, in 1905, we found an olive orchard, vineyard, and a good house at San Bruno belonging to an English company. Efforts to develop this orchard had been carried on for some years but apparently with poor success. Surface water is very scarce in this district but a great spring rises in the bottom of El Potrero Arroyo just above Mulege, about three miles from the shore of the gulf, and irrigates the fertile fields about the town. A shallow well in the bottom of the Arroyo, a few miles above Mulege, gives an abundant supply of water.

Calamahue Valley.

Calamahue Valley is a gently sloping plain about 20 miles long and one to four miles broad, beginning at an altitude of 950 feet at the mouth of Calamahue Canyon and descending a little east of north to the mouth of Calamahue Arroyo on the shore of San Luis Gonzales Bay on the gulf. It is bordered on the eastern side by the high abrupt slopes of the Calamahue Mountains and on the west by low rounded hills. The broad sandy and stony dry bed of Calamahue Arroyo winds down the middle of the valley and gives evidence of occasional floods. The lower end of the valley is shut off from the gulf by a single low ridge, through a narrow gap in which the Arroyo passes to the gulf. A shallow well of good water is located on the south side of the bottom of the Arroyo just above the gap in the hills. The only surface water in the valley is from the group of springs located at its upper end, just within the mouth of the canyon beside the ruins of the old Calamahue Mission. All of these springs are more or less strongly charged with soda and other minerals, the water from some being too bad to use and in none is it good. The desert vegetation in the bottom of the valley is small and rather sparse, being much like that near San Felipe Bay. The surrounding mountain slopes are extremely barren. This valley is one of the hottest places we visited during our trip.

The Colorado Desert.

Extreme northeastern Lower California is occupied by the southern end of the Colorado Desert.

This level or gently sloping area extends from the California border southward to San Felipe Bay, on the Gulf of California. It is bounded on the west by the Sierra Juarez and Sierra de San Felipe; on the east by the Colorado River and the northern end of the gulf. A narrow belt along the gulf coast and a much broader area in the delta district, especially near the border and about the Cocopah Mountains, are nearly level and only a little above sea level. Inland from these flats the desert plain rises gradually to elevations varying from a few hundred to over 1,500 feet above the sea along the base of the mountains forming its western border. More or less disconnected and irregular desert mountains and small ranges varying from a few hundred feet high to elevations of over 4,000 feet are scattered irregularly over this desert, especially in its southern half, where a considerable part of its total area is thus occupied. These mountains are surrounded by plains or by valleys and are separated by narrow passes.

The flood plain of the Colorado delta extends westward to the east base of the Cocopah Mountains. On this plain, near the base of the mountain, is located a small volcanic area centering at the Cerro Prieto, near which are located the curious mud volcanoes of this region. They are small mud cones a few feet high which at intervals send out small gushing overflows of warm liquid mud from craterlike openings in the tops. (See Pl. 21, Fig. 2.)

On the western side of the Cocopahs is a sink extending below sea level containing a brackish lake known as the Laguna Maquata or Laguna Salada. At times of high water in the Colorado River this lake is greatly increased by overflow from the river around the southern end of the Cocopahs. This depression, like the basin of the Salton Sea, once formed part of the great depression occupied by the northern extension of the Gulf of California, occupying all this part of the present Colorado Desert before it was filled with silt brought down by the Colorado.

Owing to their size and isolation the Cocopah Mountains form the most conspicuous mountain group of this desert area. Farther south are the Sierra Pinta, the Sierra Tinaja, and the Sierra de San Felipe, the last-named range extending in a generally southerly direction parallel to the coast to a point opposite San Felipe Bay and separating the narrow southern extension of the Colorado Desert along the gulf coast from the interior.

On the California side of the border in this region part of the Colorado Desert is occupied by the wonderfully fertile district familiarly known as the Imperial Valley. The southern part of this marvelous agricultural district lies across the border in Lower California, where within the last few years extensive development has taken place, with the town of Mexicali as its commercial center. These delta lands lie both in this part of Lower California and the adjacent part of California and are dependent on water obtained from the Colorado River and carried in canals passing through Lower California before entering California. Although having one of the hottest and most arid climates of any part of the peninsula, it is by far the most valuable agricultural area in Lower California. The lower parts of the Colorado Desert are composed wholly of silt brought down in ages past by the Colorado River. As a consequence the silt is exceedingly rich, and abundant crops grow wherever water is properly applied.

Valle de San Felipe.

Lying along the eastern base of the San Pedro Martir Mountains is a long and troughlike valley with an altitude of about 1,200 feet in its lowest part. This valley varies from 3 or 4 miles to more than 12 miles in width and has a length of about 60 miles. The narrow bottom in the northern part of the valley is occupied in part, especially opposite La Providencia Canyon in the San Pedro Martir Mountains, by series of sand dunes, and the valley slopes rise steadily to 600 or 1,000 feet on both sides to the bases of the adjacent mountains. The valley is an exceedingly arid barren desert, limited by the closing in at each end of the bordering mountains.

The eastern border of the desert is practically waterless, but water occurs at the mouths of a number of large canyons in the mountains along its western border. Along the basal slope of the mountains on the western side of the valley there is an abundant desert vegetation, but elsewhere the plant vegetation is small and gives evidence of the intensely arid climatic condition.

San Rafael Valley.

San Rafael Valley lies on the interior plateau about 20 miles by road easterly from Ensenada at an altitude of about 2,600 feet. It forms a long, slightly undulating, basinlike plain between the Coast Range and the west base of the Sierra Juarez. It lies in a generally northwesterly by southeasterly direction for a distance of 15 or 18 miles and has a width of from 3 to 10 miles, being broadest in its southern half. It appears to lie wholly within a granite formation. In the middle of the valley, almost due east from Ensenada, are some large springs, known as Ojos Negros, whence a series of swampy flats with some tules in them extend down the bottom toward Real del Castillo and drain through Arroyo San Rafael or Arroyo Guadalupe to the Pacific coast north of Ensenada. The eastern side of the valley is sandy, owing to the abundant disintegrated granite wash brought down from the Sierra Juarez. In the bottom of the valley, especially above Ojos Negros, mesquites, ephedras, and yuccas were common, while the adjacent foothills were clothed with an abundant growth of *Adenostoma*, *Eriodictyon*, *Arctostaphylos*, *Sambucus*, and of two oaks, *Quercus wislizenii*, and *Quercus agrifolia*. A little land is cultivated, mainly about the border of the valley, but it is principally occupied by a large cattle ranch with headquarters at Ojos Negros. The lower end of the valley leads to the site of the old mission of Guadalupe.

Alamo Plain.

The Alamo Plain is a gently rolling part of the main plateau, at an altitude of from 3,500 to 3,800 feet, along the westerly side of the southern end of the Sierra Juarez and separated on the north from the southern end of San Rafael Valley by a range of rounded low hills. It is about 20 miles long in an east and west direction and much less in breadth. The old Santa Catarina Mission is located on its eastern border and the small mining town of Alamo, at the east base of the Coast Range, at its western end. The plain is watered with a few small springs and waterholes and a small stream in the arroyo at Santa Catarina. The drainage is westerly through the Santa Tomas River into the Pacific. A considerable growth of California junipers formerly covered the plain and the bordering foothills, but the larger of these have been used as fuel for the mine at Alamo, leaving only the smaller growth. On the north and south the plain merges into rolling

hill country. To the southeast it gradually rises to the top of the cliffs which bound the northern side of Trinidad Valley.

Trinidad Valley.

The Trinidad Valley is a long oval basin with a gently sloping bottom, extending about 18 miles in an easterly and westerly direction, and 5 or 6 miles across in the middle, decreasing in width toward each end. It is the head of the drainage of the Rio Salado, which flows westerly through the Coast Range into the Pacific. Its eastern end forms San Matias Pass, which, at an altitude of about 3,200 feet, separates the south end of the Sierra Juarez from the north end of the San Pedro Martir Mountains. The valley thence slopes gently westward to the lower end below Campbell's ranch, where, at an altitude of about 2,500 feet, it closes into a box canyon. On the north it is bordered mainly by a high rocky escarpment, and on the south by a series of rolling foothills, extending from the west base of the San Pedro Martir Mountains.

The valley is without surface water, except some small springs and waterholes and a small stream at its extreme lower end. A good underground supply exists at shallow depths in the lower half of the valley. Its western two-thirds is an open, grassy plain with some small shrubs; the narrowing eastern third has a considerable growth of cactuses, yuccas, agaves, and other desert plants, which come through San Matias Pass from San Felipe Valley to the east. Trinidad Valley is too dry for agriculture, but with the surrounding hill slopes makes an excellent cattle range.

Llano de Los Buenos Aires, or Llano de San Augustin.

At San Fernando there is a small narrow flat-bottomed valley which extends to the eastward, through the open hills, and merges into a broad, slightly undulating desert plain known as the Llano de los Buenos Aires, or Llano de San Augustin. This plain is a part of the great central plateau lying at an altitude of from 1,800 to 2,500 feet along the middle of the peninsula and extends southeasterly from the southern end of the San Pedro Martir Mountains.

The names Llano de los Buenos Aires and Llano de San Augustin have heretofore had a local application to the more level middle parts of this plateau between San Fernando and Onyx, but here they are used to cover all this section of the plateau. The entire llano is about 28 miles across, in an easterly direction from near San Fernando to the Onyx mines (located at the edge of the foothills on its eastern border), and is over 40 miles long from its border north of San Augustin Well southeasterly to Arroyo Catavina. This part of the plateau is nearly level in places, especially between San Fernando and Onyx, but is generally more or less undulating with small scattered hills and outcroppings of bare granite. To the north the plateau reaches the extreme southern end of the slopes leading down from the San Pedro Martir Mountains. On the eastern side it is walled in by the bare, abruptly rising slopes of the mountains which parallel the gulf shore; on the western and southern sides it slopes gently southwesterly toward the Pacific and is limited by irregular ranges and groups of low rocky hills and mountains. Water is scarce but is found at the surface in the bottoms of several small canyons and arroyos. The vegetation is scanty between San Fernando and Onyx, but farther to the southeastward an extraordinarily abundant and vigorous growth of desert species prevails. This plain is limited on the southeast by the Arroyo Cataviña, beyond which, for 12 miles, to Arroyo Jaraguay, the country becomes much more broken and is covered with ridges and piles of huge granite bowlders. (See Pl. 27.) The onyx mines, which have been worked for a number of years, are located at Onyx on the east side of the Llano de los Buenos Aires. A wagon road, down which the onyx is hauled for shipment, leads thence to Santa Catarina Landing on the Pacific coast.

Llano de Santa Ana, Desierto de San Julian, and Llano de Santa Maria.

The Llano de Santa Ana lies southeast of the southerly end of the Llano de los Buenos Aires, from which it is separated by an area of broken and hilly country. It is one of the most level parts of the main plateau slope and lies along the middle of the peninsula from the extreme head of the Arroyo Calamahue southeasterly to the vicinity of Yubay, where it is limited by a small belt of knolls and broken rocky slopes. The upper or eastern border of this plain has an altitude of about 2,000 feet and is walled by the bare granite slopes of the Calamahue

Mountains. The plain extends southwesterly for 12 or 15 miles down a long slope and across the valley of the Arroyo de San Andres to the Sierra Prieta and other barren mountains paralleling the Pacific coast. The plateau on the borders of the Llano de Santa Ana is mainly rolling and marked by low scattered ridges and projecting knobs of granite. Its slopes are scored with many low, abruptly walled gulches with sandy dry washes in their bottoms leading down to the broad Arroyo de San Andres. The tinaja at Yubay contains the only known water on the trail crossing the eastern border of the Llano de Santa Ana.

The surface of the llano surrounding parts of the plateau is covered with disintegrated granite, often more or less sandy, and supports a tremendous growth of desert vegetation, which becomes a low forest in many places, frequently forming an impenetrable thorny jungle. Another open plain, known as the Desert of San Julian, extends from Yubay southeasterly by the old mission of San Francisco de Borja and through low hills into still another plain called the Llano de Santa Maria and thence descends to the northern end of the Vizcaino Desert north of Calmalli. The areas are parts of the well-marked continuous elevated interior plateau beginning at the southwestern base of the San Pedro and extending southeasterly along the west base of the main range until it merges into the Vizcaino Desert. Surface water is very scarce and mainly in small rock tanks or here and there where the underground flow in stream beds is forced to the surface by the bedrock for short distances.

San Ignacio Valley.

San Ignacio Valley is formed by the broadening of a low canyon which drains the western slope of the Santa Lucia Mountains to the Pacific. It is located near the middle of the peninsula and is only about 3 or 4 miles long by a mile or so in width. The lower end narrows into a flat-bottomed canyon 12 or 15 miles long leading down to the southern end of the Vizcaino Desert. Near the upper end of the valley several great springs rise in the bottom and supply abundant water for irrigating all the arable land in the valley and most of that in the canyon below. The valley is the site of one of the largest and most flourishing of the old missions and at the time of our visit had a population of about 1,000, closely grouped about the large, well-preserved mission church. (See Pl. 11, Fig. 1.) The valley has an altitude of about 800 feet and is located in the midst of a great lava plateau. Its drainage is southwesterly into San Ignacio Lagoon on the coast of the Vizcaino Desert. It is a very fertile spot, notable for the great number of date palms. The lava plain extends northeasterly from the San Ignacio Valley past the bases of the volcanoes of the Tres Virgines to the gulf coast and forms one of the few low passes across the peninsula.

La Purisima Valley.

La Purisima Valley is formed by the flat bottom of a high-walled canyon, varying from about 100 to 1,000 yards wide, in the midst of the great volcanic plateau. The bottom of the valley has an altitude of from 300 to 500 feet and is irrigated throughout its length by a stream giving the most abundant water supply existing in any of the canyon valleys of the peninsula. The valley is very fertile and is cultivated for a distance of about 12 or 15 miles, below which it becomes a narrow box canyon through low foothills for some miles and then opens on the northern end of the Magdalena Plains. The drainage is southwestward into the Estero de San Ramon on the Pacific coast. We were informed that a well sunk 1,200 feet in prospecting for oil in the lower end of La Purisima Canyon some years before struck artesian water, which had been flowing continuously since that time. This valley has a population of about 600 and is the site of one of the old missions.

Comondu Valley.

This is another narrow valley formed by the flat bottom of a high-walled canyon in the elevated volcanic plateau southeasterly from, and closely resembling, the valley of La Purisima. It is about half a mile wide and is irrigated for 8 or 10 miles of its upper part by the water flowing from large springs. It narrows below to a deep box canyon which ends on the northern part of the Magdalena Plains. It is one of the most beautiful valleys in the peninsula and at the time of our visit was occupied by a population of about 1,000 people. (See Pl. 13, Fig. 2.) The valley

has an elevation of about 700 feet and drains southwesterly across the Magdalena Plains to the Pacific coast. Like La Purisima this valley contained one of the old missions.

STREAMS AND OTHER SURFACE WATERS.

Owing to the scanty and irregular rainfall within its borders Lower California is poorly supplied with surface water, the only real river touching the peninsula being the Colorado, the delta of which lies on the extreme northeastern border. The long, narrow form of the peninsula, with a high divide extending practically its entire length, reduces the length of all watercourses located within its borders to the short distance from the high interior to one coast or the other. Although the peninsula is about 800 miles long, it is doubtful if any of its watercourses reach a length of 90 miles. There are hundreds of drainage channels which vary from rugged rock-walled canyons, some of which reach 2,500 feet in depth on the flanks of the mountains, to sandy or stony washes half a mile or more broad on the open plains. Except during heavy rains most of these channels are wholly dry, but in the upper parts of many of the larger canyons water rises and flows permanently for distances varying from a few rods to 10 or 15 miles before sinking again. In some canyons the water rises and sinks several times, but usually sinks finally near the border of the plains, or in the low foothills. Usually the water thus rising forms an insignificant streamlet, but in some cases it boils up through great springs which send out a good-sized creek, large enough to irrigate many hundreds of acres of land, as in San Ignacio, La Purisima, Comondu, Todos Santos, and San Bartolo Canyons. Most of the cultivated oases along the middle of the peninsula depend on the water flowing from such springs. During heavy rainstorms, especially in winter, streams often flow down the usually dry channels to the sea, sometimes for several days or even weeks in succession, but periods of several years may pass without a drop of water appearing in them.

The great number and frequently large size of the dry canyons and other drainage channels throughout the peninsula, and other signs of much erosion, might lead to the impression that a greater rainfall once prevailed. The tremendous power of such floods as occur at times through the peninsula are well shown at the mouths of the great canyons along the east side of the San Pedro Martir Mountains. Great alluvial fans, or deltas, several hundred feet deep slope down to the bottom of the valley from the mouths of these canyons, and the tops of the fans for half a mile or more below the canyons are heaped with long piles and masses of tumbled granite bowlders varying in size; numbers of them range from 3 to over 6 feet in diameter and weigh several tons. In some places these rocks are in such profusion, especially below the mouth of La Providencia Canyon on the east base of the San Pedro Martir Mountains, that they resemble glacial moraines and render approach to the canyon mouth extremely difficult. The friable character of much of the rock and observation of the enormous amount of material carried down by every flood show that present conditions are sufficient to produce the erosion so much in evidence throughout the peninsula.

As noted elsewhere, the longest slope of the peninsula is toward the west or southwest, and the longest drainage channels descend in that direction to the Pacific. Beginning at the northern border the larger of these western stream beds known to have the most extended supply of permanent surface water in some part or parts of their courses are named in their sequence as follows: Tijuana, Calabazas or Cancio, Guadalupe, Santa Clara, Santo Tomas, San Vicente, Salado, San Rafael, San Telmo, Santo Domingo, San Simon, San Javier, San Ignacio, San Jose, La Purisima, Comondu, San Venancio, Santo Domingo, Soledad, and Todos Santos. There are numerous smaller and less important canyons along the mountain slopes, which also have a little permanent water in the upper parts of their courses.

The east slope of the peninsula is narrow and has much less water than the west slope except for the huge volume of the Colorado poured into the head of the gulf. In numerous canyons along the east base of the Sierra Juarez and San Pedro Martir Mountains and elsewhere down this front of the mountains small permanent streams flow for short distances, almost entirely within the canyons except during rainy periods. The most prominent of the water-bearing

FIG. 1. —Island overgrown with cottonwood (*Populus macdougalii*), in process of erosion. Delta of Colorado. April 1[illegible].

FIG. 2. —Flood plain of Hardy River at east base of the Cocopah Mountains. April 1[illegible].

drainage courses on the east side of the peninsula are as follows: Colorado, Arroyo Grande, Canyon Diablo, La Providencia, El Tule, Matomi, Calamahue, Santa Isabel, Agueda, San Jose, Magdalena, El Potrero, Loreto, Santiago, and San Jose del Cabo.

The extreme northern and southern parts of Lower California have higher mountain masses and receive a greater volume of and more regular precipitation than the middle section. Consequently these two areas, without considering the Colorado, have the more plentiful supply of both surface and underground waters. The northern section includes the Sierra Juarez and Sierra San Pedro Martir and is the larger area with the largest total of water, but the smaller southern section, south of La Paz, has more in proportion to its size.

The Colorado is the greatest of all and the only real river in Lower California. It forms a great delta region containing much fertile land in the northeastern corner of the peninsula and pours a mighty current into the head of the gulf. Every spring and early summer there is a flood in the Colorado from melting snow in the Rocky Mountain region of the United States, which fills the ramifying channels in its lower course and overflows the lowlands between the eastern base of the Cocopah Mountains and the Colorado. (See Pl. 23.) This diverted flow reenters the Colorado through the various old channels which drain the delta. Some of the overflow from the Colorado passes by the southern end of the Cocopah Mountains into the bed of the long Laguna Maquata, or Laguna Salada, as it is variously named, which lies along the western base of these mountains. These floods build new islands and tear down old ones in the delta each spring.

It is well known that owing to the filling up of its bed in the delta by silt the channel of the Colorado has many times shifted to the east or west. In 1905 the middle channel was in use, but since then the main stream has again changed and now flows through Volcano Lake and thence by way of the Hardy Channel to the mouth.

Within a comparatively few years large irrigating ditches have been taken out of the Colorado in the extreme northeastern corner of Lower California and carried across the plains to hundreds of thousands of fertile acres on both sides of the border to the westward from this point.

Excepting the Colorado, in all the coast line of the peninsula, more than 2,000 miles in length, only five small streams flow to the vicinity of the sea throughout the year. Of these only one, the Rio Santo Domingo, north of San Quintin, has a continuous flow throughout most of its length. Of the other four, the San Jose rises and sinks several times in its channel, while the others, the arroyos of El Rosario, Todos Santos, and El Potrero at Mulege, emerge in large springs only a few miles from the sea. None of the streams flowing permanently to the vicinity of the coast enter the sea directly, as ordinarily the sea beach forms a sand bar across the mouth of each, so the stream discharges into a fresh or brackish lagoon and seeps through the sand, or sinks in its sandy bed, except El Potrero, which flows into a lagoon extending from Concepcion Bay.

As already noted, most of the surface water in northern Lower California is in the drainage system of the Sierra Juarez and San Pedro Martir Mountains. The east slope of these mountains drains toward the gulf or the delta of the Colorado and is practically waterless, except for a few small springs and small streams of clear pure water which flow down the bottoms of the larger of the deep, short canyons which gash the precipitous front of this slope. In cool weather, especially after rains, these streams flow out sometimes several miles on the sloping plain at the mouths of the canyons, but during hot weather the decrease in flow and the evaporation are so great that they often end well up in the lower part of the canyons. Several of these springs and little streams are located along the east base of the Sierra Juarez, especially in Palm Spring, Tako, Guadalupe, Palomar, Agua Caliente, Tule, and Arroyo Grande Canyons (See Pl. 24, Fig. 1). In Arroyo Grande the permanent water flows for 10 miles in the canyon bottom but sinks well above the open desert. After torrential rains along their upper courses both of these arroyos send their waters north to the basin of Laguna Maquata. Throughout most of the year along the east base of the San Pedro Martir Mountains and adjacent front of the tableland to the southeast small streams reach the mouths of the larger canyons, which include Esperanza, Diablo, La Providencia, Santa Rosa, Agua Caliente, Paral, and Matomi.

In the latter part of June, 1905, water flowed at night a little below the mouths of La Esperanza, El Diablo, and La Providencia Canyons, but owing to the heat and consequent evaporation by day the lower end of the surface water had retreated one-half or three-fourths of a mile by sunset each afternoon. Later in the season the water retreats still farther and the lower ends of the streams are said to be well up in the canyons.

On the west sides of the Sierra Juarez and Sierra San Pedro Martir nearly all the larger canyons on the main mountain slopes have small permanent streams flowing in at least a part of their length and sometimes well down to the foothills to within a few miles of the sea. Sometimes the water sinks and rises more than once in its course along the rocky or sandy canyon bottoms.

The main drainage channels leading down to the coast on the Pacific slope of these mountains are the Tijuana, San Rafael, Ensenada, San Carlos, Santa Clara, Santo Tomas, San Vicente, Salado, San Telmo, Santo Domingo, San Simon, and El Rosario. All of these drainage channels with many of their tributaries in the foothills have permanent running water in at least part of their courses, but with the exception of the Rio Santo Domingo and Arroyo del Rosario the water sinks some distance back from the coast. The Rio Santo Domingo is the only stream within Lower California which has a permanent flow from its extreme head nearly or quite to the coast. Its headwaters consist mainly of several arroyos beginning high up on the western side of the San Pedro Martir Mountains. The most important fork is known as the Arroyo San Antonio, or Arroyo La Grulla. This drains La Grulla Park at an altitude of more than 7,000 feet and descends by San Antonio ranch to unite with other tributaries. This is the main source of the Rio Santo Domingo, which reaches the Pacific north of San Quintin. About 6 miles above San Antonio ranch the arroyo has a high waterfall which Mexican engineers have estimated would yield 8,000 horsepower. Other tributaries are the arroyos of El Alcatraz, La Zanja, Santa Clara, and Valladares. One of the north forks of the Santo Domingo is known as the Arroyo de Valladares, on which are located the Valladares placer mines. Mr. A. W. Anthony worked these mines at one time and informs me that the Valladares Creek can be counted upon to give about 300 miner's inches of water for seven months in the year. A few miles south of the mines the Arroyo San Antonio, another large fork of the Santo Domingo, comes out of a canyon in the west base of the mountains at the San Antonio ranch. The water in this creek at the end of July, 1905, was 10 or 15 yards wide and varied from a few inches to 2 feet deep.

The Arroyo San Antonio is distinguished as being the only stream in Lower California which contains brook trout. We found a species living here which attains a length of 12 to 15 inches and is related to the rainbow trout of California. It was abundant in the canyon above San Antonio ranch, which has an altitude of about 2,000 feet. This trout proved to be a new species, which Dr. Evermann has named *Salmo nelsoni*. There is a strong flow of water in the headwaters of the Arroyo San Telmo, which heads on the west side of the San Pedro Martir Mountains north of the Santo Domingo. Ditches have been taken out of this stream and water carried several miles along the foothills to the Socorro placer mines a few miles from the Valladares placers. The Arroyo del Rosario, 40 miles south of San Quintin, carries a small permanent stream which rises in the dry bed of the arroyo and flows less than 5 miles down a small canyon to the seashore.

Water is scarce on the high parts of the Sierra Juarez and San Pedro Martir Mountains. A few small springs and streamlets in canyons are about all. A large pond, known as the Laguna Hanson, is located on top of the Sierra Juarez northeast of Ensenada. This pond is in a small mountain park at an altitude of about 5,400 feet and surrounded by low pine forest. It is shallow and nearly half a mile long with an irregular outline, the arms extending between ridges of granite bowlders. The bottom is rather hard and the cattle ranging there keep down all marginal plant growth, so that there is no shelter for wild fowl. Two or three much smaller ponds are located in La Grulla Meadow, a long mountain park situated at about 7,000 feet on the west side of the San Pedro Martir Mountains. (See Pl. 7.) Formerly these ponds were bordered by aquatic vegetation and frequented in summer by breeding waterfowl, but the cattle ranging there in 1905 had grazed this growth so closely that the birds had abandoned this resort. A large

spring, Ojos Negros, rises in San Rafael Valley and another large spring rises near the old mission of San Fernando, but judging from evidences of former irrigation there must be much less water at the latter point now than in the days of the early missionaries.

Here and there throughout the north as well as elsewhere in the peninsula, both in foothills and on mountain sides, occur tinajas or natural water tanks, usually formed by large potholes worn in the rocky bottoms of dry canyons or gulches. These natural tanks sometimes hold water several years in succession, during which no rain falls.

The most arid part of the peninsula lies between San Fernando at about 30° and La Paz near 24° north latitude. Within this area not a single living stream touches the Pacific coast, except during heavy rains, although the western slopes of the mountains and bordering plains are marked by large numbers of deep canyons and other watercourses. Most of these are dry throughout their length, but water flows in the upper parts of some of them, and in a few, like San Andres and Rosarito Arroyos, water rises and flows a short distance in the lower parts of their channels within a few miles of the coast. In the interior, especially in the elevated lava-covered mesa country from San Ignacio southeasterly, several of the large canyons have great springs rising in their bottoms, from which enough water flows to irrigate the narrow belt of land, amounting to several hundred acres, which extends for miles down the canyon. The canyon valleys at San Ignacio, La Purisima, and Comondu are the most notable of those which, owing to the abundance of water, form beautiful oases. San Ignacio is one of the old mission towns located in the middle of the great lava plateau. (See Pl. 11, Fig. 1.) A giant spring boils up in the bottom of the drainage bed of San Ignacio Arroyo just above the town and flows for miles down the canyon to become lost in the sand before it reaches the border of the Vizcaino Desert. A small stream comes to the surface for short distances toward the head of the Arroyo near the Sierra de Santa Lucia. At San Ignacio and below the great date palm groves other fruits and crops are irrigated from this stream, which, in addition, fills two considerable ponds by the town.

One of the largest streams of this character in the peninsula exists in La Purisima Canyon and irrigates the bottom sufficiently to support a community of a thousand or more people, although the water is not well utilized. This stream flows 12 or 15 miles along the canyon and for a considerable part of its course the bed is characterized by a series of water holes which are always full. These water holes sometimes reach a length of several hundred feet and are reported in some instances to have a depth of 100 feet or more. During dry periods a small trickling stream connects these holes while the main part of the stream bed is dry. The water supply of Comondu comes from two large springs rising close together in the upper part of the canyon. This stream has a course several miles in length and irrigates hundreds of acres of fertile land along the level bottom. (See Pl. 13, Fig. 2.) Smaller streams furnish water enough to irrigate small patches of land in the interior foothills of the west slope at San Borja, Santa Gertrudis, Purisima Vieja, San Luis Gonzaga, and a few other places.

South of the Arroyo de Comondu a number of canyons of varying size descend the western side of the lava plateau and send drainage ways out into the Magdalena Plain, some having considerable water in the upper parts of their courses which sometimes for weeks flows well out upon the plain before sinking. These are mainly the Arroyo of San Venancio, Guadalupe, Aguajitos, Jesus Maria, El Quepo, Soledad, San Vicente, San Gregoria, La Junta and San Hilario. The Guadalupe and Soledad are the largest of these.

Along the entire gulf coast the only stream, except the Colorado, which permanently reaches the shore is at Mulege, where a great spring rises in the bottom of the Arroyo del Potrero, about 3 miles above the sea, and flows enough to irrigate the fertile bottom and thus support the town. For about 18 miles above the spring the bottom of the Arroyo del Potrero is dry and thence up to its source among the mountains a small amount of water rises at intervals and flows short distances along the bottom.

Numerous dry channels lead down to the coast from the bordering mountains along the short easterly slope of the peninsula south of the San Pedro Martir Mountains. A few of these

have a little water in the upper parts of their channels. Among these may be mentioned the following arroyos: Matomi, Santa Maria, San Francisquito, Calamahue, Santa Agueda, and Loreto. The water in the Arroyo de Santa Agueda is about 10 miles inland and through a pipe line supplies the mining town of Santa Rosalia, which contained about 8,000 inhabitants. Another small stream at Loreto supplies water for irrigating a small amount of land.

The extreme southern end of the peninsula south of La Paz is more plentifully supplied with surface water than any other equal area in Lower California. Small streams exist in the upper parts of all the large canyons in the main range from the Sierra de la Laguna to within a few miles of Cape San Lucas, and in several instances reach the basal lowlands along the east slope. Springs are rather scarce in this region and usually occur in or near the bottoms of canyons and gulches. In the mountains the springs are all small, but much larger ones occur in the lowlands. The only stream which flows permanently to the sea on the Pacific coast of the cape district is at Todos Santos. There, within 3 miles of the coast, a great spring gushes from the bottom of the drainage way leading from a large canyon on the northwestern side of the Sierra de la Laguna and irrigates hundreds of acres of sugar cane in a pretty valley on its way to the sea. The small town of Todos Santos, located at the upper end of this irrigated area, is wholly dependent upon the land irrigated by the spring. Formerly the spring flowed from a point a mile or more above its present location, but suddenly became dry and soon after burst forth at the lower point, thus causing the abandonment of a broad strip of cultivated land.

South of Todos Santos several large canyons cut the precipitous west slope of the Victoria Mountains and extend through the foothills to the sea as strongly marked drainage channels. In the upper parts of the canyons small streams occur, but lower down they sink and leave the broad sandy or rocky beds of the washes dry, except when heavy rains send down brief floods. Throughout the cape district, as well as elsewhere in Lower California, the deeply cut, dry drainage channels can be readily accounted for by present climatic conditions, in view of the friable character of the rock and the tremendous erosion caused by occasional floods.

On the east side of the cape district, nearly opposite Todos Santos, the giant spring of San Bartolo breaks out in the dry bed of the canyon of the same name. We did not visit this but Dr. Eisen has estimated the permanent flow to be about 5 cubic feet of clear cold water per second. This supplies water enough to irrigate several hundred acres of cultivated land along the steep sides of the canyon and to form a small stream about 4 miles down its bottom. There is another smaller spring near La Palma. The San Jose River, at the southern end of the peninsula, is the largest and most important stream in the cape district. It is over 50 miles long and the main branch, the Arroyo Miraflores, rises northwesterly from Miraflores in the high Sierra San Lazaro. It rises near the summit of the Sierra and flows southeasterly for about 15 or 18 miles to the village of Miraflores and then southerly down the valley through the town of San Jose del Cabo to the sea a mile beyond. The stony bed of the river through the valley is over half a mile broad in places and at flood during heavy storms for a week or more at a time it is sometimes covered by a roaring and impassable torrent. Ordinarily the channel is occupied by a small creek which rises and sinks at intervals, but comes to the surface in greatest abundance near the sea where there is a never-failing flow to the beach. It has no tributaries from the east, but a series of large drainage channels lead into it from the border of the valley on the west. The largest of these from San Jose northward, are the Arroyos Santa Rosa, San Lazaro (passing Santa Anita Ranch), San Miguel, San Ignacio, Caduano, and Miraflores. The latter is the largest of all, a strong current flowing down its canyon and into the valley all the year. Most of these streams flow permanently within their canyons, but during the dry season the smaller ones sink in the sand on reaching the border of the valley. At flood any one of them may increase to a roaring torrent down the steep canyon bottoms transporting great quantities of bowlders, so that the broad stream beds, often 100 yards or more wide, are often covered with tumbled masses of water-worn rocks that in places render passage on horseback impossible. The Arroyo Miraflores is very rocky and shows evidences of fierce floods many feet deep, though at the time we ascended its course in January it was a small clear brook. Even when the courses of the tributary streams in the valley are dry, they always have an underground flow which feeds the

main stream. An aggregate of several thousand acres of land are irrigated along the course of the San Jose and its tributaries, the largest single area being on the flat lying between the town of San Jose and the mouth of the river.

The mouth of the San Jose is usually shut off from the sea by a heavy bar of sand built up by the waves. The water is thus held back to form a long narrow fresh-water lagoon immediately back of the beach. At flood time the water from the river backs up here until it spreads over most of the adjacent cultivated fields. At such times, if the water does not break a passage for itself through the bar at the mouth, the people dig a channel across the beach and thus drain it into the sea.

In the southern cape district the drainage system of the Rio Santiago is next in importance to that of the San Jose. It is separated from the valley of San Jose by a ridge lying north of Miraflores which extends easterly from the Cerro Blanco of the Sierra San Lazaro. From the northeasterly slope of the Cerro Blanco to and including the easterly slopes of the Sierra de la Laguna, all the drainage leads into the Santiago, passing the village of this name and thence into the gulf. The stream in El Sauz Canyon is the southernmost tributary of the Santiago from the Sierra de la Laguna; to this may be added the Arroyos de la Chuparosa, San Antonio, and La Laguna. A small stream flows down the little Laguna Valley from the higher slopes of the Sierra de la Laguna and lower down joins with a small stream from San Antonio Canyon before reaching the Santiago. There is a permanent flow in the Santiago to a small lake about half a mile long and one-fourth of a mile wide at Santiago village, but beyond this to the gulf during the dry season the channel is usually dry. A broad dry wash leads for several miles down a slope from the southerly end of the Sierra San Lazaro to the flat near the beach at Cape San Lucas. Some very small streams flow a short distance in canyons at the head of this drainage channel, but are quickly lost in the sand. The abundance of fresh water near the surface on the flat back of the beach at San Lucas gives evidence of a considerable underflow down this channel.

In Lower California fresh water occurs in tinajas, or natural rock tanks, much more often than elsewhere. A tinaja is almost always a pothole or small depression worn in the rocky bottom of a gulch or small canyon in which rain water collects, and in the larger ones it is often held through several dry seasons. But for the existence of these natural tanks, which ordinarily vary from a few feet to 6 or 8 yards across and of any depth up to 10 or 12 feet, travel would be practically impossible over a large part of the peninsula. Exceptionally large tinajas occur here and there, like the Tinaja de San Juan, a few miles northerly from San Ignacio. This is an oblong basin, more than 100 yards long and 10 to 20 yards broad in the bottom of a shallow drainage channel on a flat lava-covered mesa. At Yubay the tinaja is a rounded pothole in the granite bedrock at the mouth of a canyon cutting through a low granite ridge. The Tinaja de Santa Clara is a large oblong pothole in the bed of a small canyon cut in the lava of Santa Clara Mountains. All of these tanks are readily accessible for man or beast, as are hundreds of others here and there throughout the wilderness of barren mountains on the peninsula. Others, however, are located high up in rugged and almost inaccessible canyons or in deep narrow holes so walled about that they can be found only by accident and the water obtained only by use of a rope. The few tinajas in the Cocopah Mountains are reported to be of this character. Tinajas are more numerous in gulches and small canyons than in large ones, because in the latter the mass of wash material carried by floods fills up the depressions in their beds.

Ojo de Liebre, near the head of Scammon Lagoon, on the Vizcaino Desert, is permanent, and Funcke reports that when grass is plentiful on the surrounding plain a considerable number of half-wild horses water there This spring is marked by three cottonwood trees. (See Pl. 12, Fig. 1.)

UNDERGROUND WATERS.

Lower California is characterized by a great number of watercourses leading from the high interior down to the sea. Many of these are broad enough to accommodate fair-sized rivers, some even reaching more than half a mile in width, and nearly all have deep beds of sand and

gravel which at ordinary times are dry throughout the larger part of their courses. Most of the larger washes head well up in the high interior and some have running water in their channels for miles, while others have running water at one or more places where it has been forced up by the bedrock only to sink a short distance below. An underground flow in the beds of such streams is thus proved, and it evidently exists in practically all of the larger channels, although for miles there may be no surface indication. The giant springs at San Ignacio, Mulege, Todos Santos, and San Bartolo, all rising in dry drainage channels, are examples of the amount of this underflow in some cases. Nearly all of the drainage channels are dry on the surface near the coast, but digging at their mouths on the flats, just back of the beach, has developed good water in many places within a few feet of the surface, as at San Felipe Bay, Calamahue Landing, La Paz, Cape San Lucas, and elsewhere. It is certain that water can be found in this manner at the mouths of many other washes. In addition some of the coastal plains are more or less generally underlaid with water at depths varying from 10 to 60 feet, as on the San Quintin and San Bruno Plains, about La Paz Bay, and at Cape San Lucas. Artesian water is reported to have been struck at a depth of about 1,200 feet near the mouth of La Purisima Canyon and will undoubtedly be found in various other localities.

The general "lay of the land" and character of the vegetation frequently give very positive indications of the presence of underground water. An unusually heavy growth of mesquite is a good indication of water. Such a fine growth of mesquites occurs a few miles above Mulege, in the bottom along El Potrero wash. A similar growth indicates water over a considerable area near Santo Domingo ranch on Magdalena Plain. The growth of fig and other planted trees on the ranch south of the San Simon River near San Quintin also indicates water a few feet below the surface. Water has been found in shallow wells at a number of ranches on Magdalena Plain and undoubtedly exists in many other places.

The water holes known as Tres Posos between the north ends of the Sierra Pinta and Sierra de las Tinajas, and in the flat at San Felipe Bay are only about 3 feet deep. They contain fairly good water and probably mark the underground flow from Arroyo Grande and from the San Pedro Martir Mountains, respectively.

The well at Calmalli is said to be about 50 feet deep, that at Campo Aleman 90 feet, and that at San Augustin on the Llano de los Buenos Aires about 50 feet. With cheap fuel or electric power many small or medium-sized ranches might be maintained by water pumped from these underground supplies.

COASTAL ISLANDS.

A long series of islands border the coast of Lower California, beginning with the Coronados group on the Pacific side near the northern border and extending thence around the coast to the head of the Gulf of California. From their proximity to the coast and the comparative shallowness of the intervening water, and the close similarity or identity of the geological structure on the islands and the adjacent shore, it is apparent that most, if not all, of them once formed part of the mainland of the peninsula. In addition, the plant and animal life in general are so nearly identical with those of the adjacent shore of the mainland as to complete the evidence of their origin. Some of the islands of the gulf, however, have a few notable species not represented by close relatives on the peninsula. The most striking of these among the plants are the viznaga (*Echinocactus digueti*) and among the reptiles, an iguana (*Ctenosaura hemilopha*) and a chuckwalla (*Sauromalus hispidus*).

With few exceptions the islands on both coasts of the peninsula are high and rocky with precipitous shores and few landing places. Severe desert conditions usually prevail and most of the islands lack fresh water. The islands of the southern end of the gulf are much better known then those farther north. For this reason few of the gulf islands are described here. Some of the smaller islands are of special interest on acount of their breeding places for waterfowl. Among these the island of San Ildefonso is known to be the great breeding center of Heermann's gulls. Although situated in the middle of the gulf, the island of San Pedro Martir is the breeding resort of the blue-footed and Brewster's boobies. While Guadalupe Island is

so far offshore that it can not be classed among the coastal islands, it is included here in order to complete the account of the islands off the Pacific shore of the peninsula.

Coronados Islands.

This group is a series of four small rocky islets about 5 miles long, lying in a northwest by southeast direction, a few miles south of the northern boundary and about 7 miles offshore on the Pacific side of the peninsula. They are within plain view and about 15 miles southwest from the entrance to San Diego Harbor, southern California. They all rise boldly from the sea, their shore lines consisting mainly of wave-washed cliffs. The southernmost and largest of the group is about 2 miles long north and south and half a mile broad. Its shore line is formed by high cliffs except in a small bay in the middle of its eastern shore where boats can land. The summit of the island is covered with rounded hills rising to an altitude of 672 feet near the southern end. The two middle islets are barren rocks rising precipitously 100 and 250 feet above the sea. The second largest, the most northern of the group, about a mile long and one-quarter mile wide, is surrounded by cliffs except on the southern side, where a landing can be made. This island is a narrow rocky ridge covered with sharply sloping hills rising over 460 feet above the sea.

These four islets are evidently the remnants left from the erosion of a former single large island. No fresh water is found on any of them. It is reported that the middle islets once formed a favorite resort for the sea elephant. At present a few sea lions and harbor seals haul up on the shores. The islets are treeless and have only a few small shrubs, but are covered with an abundant growth of herbaceous vegetation. The southernmost is overgrown with wild oats, and the northern one has much of its southern slope covered with a mat of the curious ice plant (*Mesembryanthemum crystallinum*). The only land mammal reported from here is a white-footed mouse (*Peromyscus maniculatus dubius*).

The Coronados are the breeding places of petrels, auklets, and other sea fowl, and their proximity to San Diego has caused them to be repeatedly visited by American ornithologists, including A. W. Anthony, J. Grinnell, A. B. Howell, the writer, and others. A song sparrow (*Melospiza melodia coronatorum*) has been described as peculiar to this limited area. Many land birds, especially the California Valley quail, fly back and forth over the short distance to the mainland. Several lists of the birds of the Coronados have been published and about 50 species are known to occur there.

Todos Santos Islands.

This is a small group of two islets and outlying rocks extending in a northwesterly and southeasterly direction immediately in front of Todos Santos Bay, off Ensenada, and only 3 miles from and in line with Punta Banda, the cape at the southern side of the bay. A long line of detached rocks stretch from the point of the cape directly toward the largest islet, with which they are connected by a submarine ridge, showing that the islets were once part of a long narrow cape, of which Punta Banda is the remaining base. The southernmost and largest of the islands is about 1¼ miles long and half a mile wide. At its northern end this islet forms a low plateau, but to the south rises into rounded hills a little more than 300 feet high. The shore line is rocky and precipitous, rising in cliffs 20 to nearly 200 feet high, and the only landing is on the northeastern side. The smaller islet lies northwest of the larger one, from which it is separated by a narrow channel. It is entirely a low plateau, a continuation of that forming the northern end of the larger islet, and has an extreme elevation of 55 feet above the sea, and its shore line is almost continuously precipitous. There is no fresh water on either islet. Both are covered with an abundant growth of herbaceous vegetation and in sheltered places on the larger islet are small patches of low shrubs. Cholla cactuses (*Opuntia*) are extremely abundant on the more level areas, necessitating some care in avoiding them. These islets are so near the mainland that the conditions are nearly the same as there except that they receive a little more moisture from the damp sea winds. The only two land mammals on the islets are a wood rat (*Neotoma anthonyi*) and a white-footed mouse (*Peromyscus maniculatus dubius*), both of which are extremely numerous and are close relatives of forms living on the adjacent mainland. A

few harbor seals and sea lions were seen about the shore, and sea otters were formerly numerous in the adjacent kelp beds. There are no birds peculiar to these islets, but a few species of waterfowl breed here and the nest of a bald eagle was found on the top of a rocky pinnacle just off the northern end of the larger islet. Fifty species of birds have been observed on the Todos Santos Islands, most of them of sporadic occurrence, but western gulls and cormorants breed there.

San Martin Island.

San Martin is a small rocky island about a mile in diameter and rounded-triangular in form, lying a few miles offshore to the northwest of the mouth of San Quintin Bay. On the northeast side the shore is low with a small sandy beach and a small rounded tidal lagoon where sea elephants and sea lions formerly resorted in large numbers to breed. Elsewhere the shore is rugged and precipitous, rising from a few feet to over 150 feet above the sea, the highest cliffs facing south. The entire surface is covered by extremely ragged and broken beds of lava, full of numerous pits, caves, jagged points, and sharp ridges, over which it is extremely difficult to travel. The middle of the island is occupied by two volcanic peaks, the highest reaching an altitude of about 470 feet, from which the slopes extend down on all sides to the cliffs forming the shore line. One of these peaks contains an old crater. There is no fresh water on this island. The lava is covered with an abundant growth of lichens. The most notable flowering plants are some cactuses and a large velvety white cotyledon with orange red flowers (*Dudleya anthonyi*).

San Martin is one of the guano islands of this coast, and we found it occupied as a breeding place by colonies of cormorants and brown pelicans. Some extraordinarily large fish-hawk nests were perched on projecting knobs of lava a few feet above the general level. On May 4, 1903, A. S. Bunnell saw gopher snakes and "alligator lizards" here. The only land mammals are a wood rat (*Neotoma martinensis*) and a white-footed mouse (*Peromyscus maniculatus geronimensis*).

This island was once noted as a great resort for fur seals and sea elephants, both of which are now extinct there. The exploring ship *Herald* was off San Martin in October, 1846, and Dr. Seemann records that "the rocks were swarming with seals; we had never seen them in greater abundance; and their howling, shrieking and barking rendered them most unpleasant neighbors."[1] During his visit to San Martin on May 4, 1903, Bunnell found several great blue herons nesting there, but they were absent at the time of our visit in August, 1905. He also noted the presence there of about 40 ospreys. About 30 species of birds have been recorded from this island.

San Geronimo Island.

This island lies 5 miles offshore near the south side of Rosario Bay. It is a low rocky islet about three-quarters of a mile long and less than one-third of a mile wide, surrounded by low cliffs 10 to 50 feet high, above which the surface forms a plateau sloping up to a hill about 130 feet high near the middle and to two smaller hills near the northern side. The islet is waterless and surrounded by kelp beds and outlying rocks. Its vegetation is very scarce and stunted. The only land mammal is the white-footed mouse (*Peromyscus maniculatus geronimensis*), which is extremely abundant. Numerous harbor seals frequent the reefs on the northwestern side. Twenty-eight species of birds have been observed here, of which auklets, gulls, shearwaters, cormorants, and pelicans breed. The surface of most of the level parts of the island is of loose, soft soil, and at the time of our visit in August, 1905, was honeycombed with the old burrows of shearwaters, but none of these birds were there at the time. San Geronimo is another well-known guano island of this coast.

Cedros Island.

Cedros Island was discovered by Francisco Ulloa in 1539 and named by him Isla de Cedros; hence the commonly used "Cerros" Island is a misnomer.[2] Although discovered at so early a

[1] Seemann, Voyage of the *Herald*, Narrative, I, pp. 119–120, 1853.

[2] Eisen, Bull. Amer. Geog. Soc., XXXIII, pp. 64–66, 1901.

date by the Spaniards, Cedros Island has been explored and made known almost entirely by the visits of American naturalists within the last 60 years. J. A. Veatch spent some time there in 1859. Lyman Belding visited it in October, 1882, and A. W. Anthony at different times between 1887 and 1897. W. W. Brown was there during most of April, 1906, and the Townsend expedition on the *Albatross* visited it in the spring of 1911. With the exception of the botanical exploration by Dr. Veatch and Dr. J. N. Rose of the Townsend party, most of the work on the island has been the collecting of birds and mammals.

Cedros Island lies about 10 miles off Point San Eugenio on the mainland; it is roughly wedge-shaped, having a length of 21 miles north and south and a breadth of about 3 miles near the northern end and 9 near the southern end. The island is abruptly mountainous, Cedros Peak, the highest point, reaching an altitude of about 3,950 feet, while other peaks give it an irregular and broken interior. Much of the island rises above 1,500 feet and its surface is rocky and sandy. Dr. Veatch states that the island is formed by three nearly parallel mountain ridges extending diagonally across it from northeast to southwest, the northern ridge being of granite and others of shale, sandstone, and other rocks.[1] He adds that most of the eastern shore of the island is precipitous, often rising abruptly several hundred feet, but its front is broken in many places where there are good landings. Elsewhere the coast line is abrupt and rocky. The northern part is apparently most fertile, especially on the western slopes and crests of the mountains exposed to the cool damp northwest winds. The crests and slopes of the mountains on the northwestern point of the island down to about 1,500 feet are covered with a growth of cedars (*Juniperus californica*) and pines (*Pinus muricata*), some of the latter attaining a height of 50 to 70 feet. A species of dwarf oak occurs and numerous other shrubs and flowers, including the California holly (*Heteromeles arbutifolia*), which grows in the pine forest. On the more desert eastern and southern slopes of the island the elephant wood (*Pachycormus discolor*), various cactuses, and other desert vegetation like that of the adjacent mainland prevails. There are two main watering places on the island, the one most used being near the beach on the eastern side, where at a point marked "watering place" on the charts fishermen and others obtain water from a spring which trickles out of a rock a few feet above sea level and is marked by a patch of bulrushes. Mr. Belding notes that there are other patches of bulrushes on the same shore of the island, which would indicate that water might be found at these points.[2] Water is found also in the interior at a mining camp and elsewhere near the northern end.

In writing of Cedros Island Capt. Scammon tells us that seals and sea elephants once basked on the shores of this isolated spot in vast numbers and that in years past its shores teemed with sealers and with sea elephant and sea otter hunters. The remains of the rude stone houses once occupied by these hardy men still exist in many convenient places. One of these houses on the west side was of large dimensions, a rough measurement making it about 40 feet square.[3]

Gold and copper mining has been carried on in a small and desultory way on this island for years but has not resulted in any permanent settlement.

All the known species of land mammals on Cedros are peculiar to the island, types of which were collected by Mr. Anthony. They include a mule deer, a cottontail rabbit, a wood rat, a white-footed mouse (*Peromyscus*), and a pocket mouse (*Perognathus*). Mr. Anthony writes me that he has seen signs on the island of a pocket gopher (*Thomomys*), as well as the tracks of a fox, and has heard reports of the presence of a rock squirrel (*Citellus*) about the tops of the mountains. The fox tracks might have been either those of the gray fox (*Urocyon*) or the small desert fox (*Vulpes*).

The exploring ship *Herald* stopped at Cedros in October, 1846, and Dr. Seemann reported wild goats to be abundant there. The deer have been killed to supply mining camps with meat until the existence of the species has been endangered. The sea otter, sea elephants, and fur seals which were once so numerous about its shores are now gone. Only 40 species of birds have been observed on Cedros, and owing to the proximity of the island to the main-

[1] Hesperian, III, pp. 532–533, 1860.
[2] Proc. U. S. Nat. Mus., V, pp. 530–531, 1883.
[3] Scammon, in Appendix to Browne's "Resources of the Pacific Slope," p. 129, 1887.

land few peculiar forms are known. W. W. Brown records that in April, 1906, he found birds not only extremely scarce on the island but very shy. He collected three species of snakes and five of lizards and saw no others.[1]

San Benito Islands.

The San Benito group consists of three small barren islands evidently formed by the erosion of a single large island, which at a remote period was undoubtedly connected with the mainland by Cedros Island. This group lies 15 miles west of the northern point of Cedros and is about 5 miles across from east to west by nearly 2 miles from north to south. According to Bunnell these islands are formed of a flaky shale and the more level areas are covered with a brown powdered earth.

West Benito, the largest island, measures about 2 miles from east to west by 1½ miles from north to south. Its shores are bold and rocky and the surface consists of an elevated plateau, with a rounded hill near its middle rising 660 feet above the sea. Middle Benito, the smallest of the group, is a low flat island, its highest part being only 82 feet above the sea. East Benito, the second in size, has four prominent hills, the highest of which reaches an altitude of about 420 feet. There is no fresh water on any of these islands.

The vegetation consists mainly of some cactuses, agaves, and small shrubs. A single species of lizard is found here. Twenty-six species of birds are known from these islands, of which McGregor's house finch and the San Benito sparrow are peculiar to this limited area. These islands are favorite nesting places for Cassin's auklet, Xantus's murrelet, and the black, Socorro, and least petrels. No land mammal occurs there, but the shores formerly abounded with sea otters, fur seals, and sea elephants, all of which are now absent. In May, 1903, Bunnell saw about 300 sea lions there and some harbor seals.

The San Benitos have been repeatedly visited by American ornithologists, including A. W. Anthony, W. W. Brown, and members of expeditions sent out by the California Academy of Sciences.

Natividad Island.

Natividad lies about 4 miles northwestward from Point San Eugenio on the mainland and is almost in a line between this point and Cedros Island. It is 3¾ miles long in a northwest to southeast direction and varies from half a mile in width at its northwestern end to about 1½ miles near the southeastern end. It is barren and hilly, rising to a height of nearly 500 feet in the middle and bordered mainly by steep rocky shores. On the southeastern end there is a sandy beach about half a mile long. Large areas of the island are covered with loose sandy soil, dotted with the burrows of the black-vented shear water and Cassin's auklet. Colonies of cormorants also frequent Natividad, which is one of the well-known guano islands of this coast. There is no fresh water here. Vegetation is scarce, but giant cactus and a smaller cactus are found and a few shrubs are generally distributed. The ice plant (*Mesembryanthemum*) is the most abundant plant and carpets much of the island. One or more species of small lizards live here. The first notice of bird life on Natividad Island is in the record of the visit made by Padre Taraval in 1732.[2] In 1897 A. W. Anthony visited the island and later published his observations on the colony of shearwaters whose burrows are so notable a feature of this spot. An expedition from the California Academy of Sciences visited the island in May, 1903, and in April, 1906, W. W. Brown spent a short time there and afterwards his observations were published in the Condor for May and June, 1907. Only 16 species of birds are known from this island, although numerous others must occur occasionally. The principal birds are Cassin's auklet, the black-vented shearwater, the California brown pelican, the cormorant, and the western and Heermann's gulls. This island is notable as the nesting place of thousands of black-vented shearwaters.

The only land mammal on Natividad, a white-footed mouse (*Peromyscus maniculatus geronimensis*), is extremely abundant. Sea otter, sea elephants, and Guadalupe fur seals once frequented its shores in large numbers but are now gone. A few sea lions and harbor seals still occur.

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[1] Condor, IX, pp. 77–78, May–June, 1907.

[2] Venegas, Noticias de California, II, p. 436.

San Roque Island.

San Roque is a rocky islet lying 2 miles offshore in front of San Roque Bay. It is approximately three-quarters of a mile long by 1 mile wide and rises about 50 feet above the sea. It has no fresh water. Like most other islands along this coast, it is a breeding place for cormorants and a few sea birds. A single land mammal, the white-footed mouse (*Peromyscus maniculatus cineritius*), is peculiar to it.

Asuncion Island.

This island lies less than 6 miles southeast of San Roque and three-quarters of a mile south from Asuncion Point on the mainland, which forms the southeastern limit of San Roque Bay. It is only a mile long north and south and a quarter of a mile wide. Asuncion is a barren island of sandstone formation, the highest point rising about 165 feet above the sea at its southern end. It has no fresh water. It is frequented by a few species of sea birds, but has no land mammals.

Magdalena Island.

This long, narrow, irregular island, over 50 miles long and from 1 to more than 5 miles wide, lies close inshore and nearly parallel to the coast of the peninsula. The northern three-fifths of the island extends in a northeasterly by southwesterly direction, separated from the mainland by a narrow tidal lagoon varying from half a mile to 3 or more miles wide; the southern two-fifths of the island turns sharply in a northwesterly by southeasterly direction, forming Cape San Lazaro at the angle and inclosing the western side of the well-known Magdalena Bay. The narrow tidal lagoon separating Magdalena and other sandy islands to the north from the mainland is from 1 to 5 fathoms deep. It is navigable for boats throughout its length and is the regular route by which produce is brought down to the bay from as far north as Comondu Valley.

With the exception of a solitary rocky hill rising to an altitude of 1,275 feet close to Cape San Lazaro, at the western angle of the island, and a narrow rocky ridge 10 or 12 miles long and 1,250 feet high, occupying the extreme southern end, Magdalena Island is composed of low sand dunes and sandy flats rising from tide level to an elevation of about 25 feet. The two above-named rocky elevations appear to have been formerly separate islands which have been united by the low sandy plain built by the sea.

The high rocky ridge which forms the southern end of the island shuts in the west side of Magdalena Bay from the Pacific and ends as a bold headland on the west side of the entrance to the bay. On the west side of the bay near the northern end of this ridge is the village of Magdalena Bay. (See frontispiece.) A line of sand dunes form the edge of the low mainland plain on the northern and eastern shores of the bay. The tidal lagoon separating the northern three-fifths of the island from the mainland is extremely irregular and contains scattered islands. At its southern end it opens out to form Magdalena Bay. It varies from 1 to 5 fathoms in depth and at especially low tides can be forded near the middle by men and horses.

There is no good fresh water on this island, but brackish water can be obtained by digging in the flats north of the village.

Magdalena Bay is about 15 miles across and is almost completely landlocked. For years it has been the favorite winter practice resort for the American Navy. About the middle of the last century it was a favorite resort for the whaling fleets operating on this coast and later became the headquarters for the orchilla industry. An American company, known as "The Chartered Co.," of Lower California, held a concession covering a coastal strip several leagues broad, extending north to Scammon Lagoon. The only business being done at the time of our visit was the selling of a few cattle to vessels calling at the bay and the shipment of some sea turtles to San Francisco. The borders of the lagoon north of the bay and islands in it are covered with mangroves. The remaining vegetation of Magdalena Island consists mainly of some of the desert species which grow on the adjacent Magdalena Plain, but the giant cactus and some other prominent species of the plain are absent. On sheltered slopes and benches north of the village, near the northern end of the high rocky ridge, there is a good growth of desert vegetation, including among numerous others such common genera as *Abutilon*, *Fouquieria*, *Jatropha*,

Pedilanthus, Terebinihus, Wilcoxia, Opuntia, and *Lamaireocereus;* elsewhere, especially on the rocky slopes, vegetation is much smaller and more sparingly distributed.

The birds of this island are the same as those on the adjacent coastal plain of the mainland. A few of the mammals are peculiar to the island, including a pocket mouse, a pocket gopher, and a white-footed mouse. Jack rabbits occur here and on Santa Margarita Island. Coyotes are extremely common, and occasionally mule deer occur near the northern end. While the climate of Magdalena Island is somewhat modified by the cool breezes of the Pacific, yet it is so far south that it has much less fog than the coast farther north and being extremely dry arid tropical conditions prevail.

Santa Margarita Island.

Santa Margarita Island lies southeast of the southern end of Magdalena Island and incloses Magdalena Bay on the south. Its northwestern end presents a bold headland facing the southern end of Magdalena Island across a channel a little more than 3 miles broad, forming the entrance to the bay. From this point Santa Margarita extends nearly 25 miles southeasterly approximately parallel to the trend of the mainland coast and varies from 2 to 5 miles in width. The island is mainly mountainous in character, the barren rocky slopes rising to peaks along a crest extending lengthwise of the island and varying from 1,000 to over 1,800 feet high, but separated into two sections as described below. The shore line is almost entirely rocky and precipitous, except in the middle, where a low pass more than a mile broad in its narrowest place and about 100 feet above the sea separates the island into two nearly equal islandlike parts. On the northeastern side of the island this pass is a little more than a mile wide, but broadens to a low plain extending more than 5 miles along the southwestern side between the mountain ridges and the shore. On the inner or northeastern side of the pass are some small lagoons full of mangroves where cormorants and man-of-war birds nest. Close by are the ruins of a small experimental factory built long ago for canning sea turtles. This business failed after a short trial. Through the pass on the seaward or southwestern side the low plain is bordered along the beach by a belt of sand dunes. On the flats just inside the dunes, fresh water lies close to the surface. We found there a deserted ranch with a few date palm trees nearly buried in the encroaching sand dunes.

Santa Margarita is generally barren and desertlike in character with a scanty vegetation derived from the mainland shore. The hills and mountain slopes are extremely barren. The low area in the middle contains a more abundant vegetation, mainly the same species observed on Magdalena Island. Among the most notable species seen were the giant cactuses (*Pachycereus calvus* and *Pachycereus pectenaboriginum*), the "pitahaya agria" and "pitahaya dulce" (*Lemaireocereus gummosus* and *L. thurberi*), the ocotillo (*Fouquieria peninsularis*), *Jatropha canescens,* and *Pedilanthus macrocarpus.*

The few land birds noted were the same as those of the mainland, such as caracaras, fish hawks, sparrow hawks, gilded flickers, Lower California flycatchers (*Myiarchus*), Xantus jays, ravens, rock wrens, and San Lucas cactus wrens. As already noted, the man-of-war birds and Farallon cormorants (*Phalacrocorax dilophus albociliatus*) nest on the mangroves about the lagoon on the inner side of the island. California brown pelicans also nest in considerable numbers farther south on the island.

Margarita Island incloses on its northeastern side Almejas Bay, which communicates with Magdalena Bay by a narrow channel in which lies Mangrove Island. This is a low sandy island overgrown with mangroves and forming a great nesting place for cormorants and some other waterfowl. Near the head of Madgalena Bay is a low, flat, and bare sandy island only a little above tide level, which is a resort for enormous numbers of cormorants, pelicans, and gulls. Owing to the number of sea fowl which make this a resting place and which formerly bred there, this is a guano island.

Although, like Magdalena Island, so near the coast and having the same general character of vegetation and climatic conditions, Santa Margarita contains several forms of small mammals peculiar to it. The jack rabbit (*Lepus californicus magdalenae*) is somewhat different from

its relative of the adjacent shore. The wood rat is similar to the one on the mainland. The white-footed mice, pocket mice, and kangaroo rat are all forms peculiar to this island.

Ceralvo Island.

This is the southernmost of the islands in the Gulf of California and the nearest point lies 4 miles off the eastern coast of the peninsula southeast of La Paz Bay. Ceralvo is over 15 miles long approximately northwesterly and southeasterly and 4 miles wide. The southern end of the island is within 3¾ miles of Ventana Point, the island lying on the eastern side and partly inclosing Ventana Bay. Ceralvo is occupied by a single high mountain ridge extending nearly its entire length and reaching altitudes of 2,265 and 2,477 feet near the northern and southern ends, respectively. The slopes of the mountains are steep, and almost the entire shore line is high, rocky, and precipitous. At the extreme southern end the island descends to lower slopes and ends in a limited sandy flat on the shore backed by low benches and ascending slopes. This affords the only comfortable landing place.

The island is extremely arid and desert in character and has no fresh water nor inhabitants. Deposits of old pearl oyster shells on the sandy flat at the southern end indicate that the island was once the resort of pearl fishers.

Ceralvo appears to have been connected with the mainland through the extension of the southern end of the island to Ventana Point, as indicated by the shallowness of the sea between them. There is a much greater depth between the western side of the island and the opposite part of the mainland. That this island was once part of the mainland is indicated by the identity of the geological formation on their adjacent shores.

The vegetation is a mixture of Arid Tropical and Lower Sonoran species, mostly identical with those of the neighboring mainland. The great viznaga (*Echinocactus digueti*), however, appears to be peculiar to this and other islands of the gulf. Other prominent plants noted here are *Olneya tesota*, *Fouquieria peninsularis*, *Elaphrium microphyllum*, *Brayodendron texanum*, *Ibervillea sonorae*, *Jatropha spathulata*, *Pedilanthus macrocarpus*, *Lemaireocereus thurberi*, *L. gummosus*, *Pachycereus calvus*, and some opuntias.

This island is noted for the occurrence of many iguanas which are not known from the mainland of the peninsula but do occur on some of the other islands farther north in the gulf. Fish hawks, sparrow hawks, ravens, black-throated sparrows, San Lucas house finches, and rock wrens were among the few land birds noted here.

Only two land mammals are known from Ceralvo, the pocket mouse (*Perognathus penicillatus siccus*) and the rock mouse (*Peromyscus eremicus avius*). Both forms are peculiar to the island and closely related to mainland species.

Espiritu Santo Island.

Espiritu Santo Island walls in a part of the eastern side of La Paz Bay and is about 10 miles long north and south and 4 miles wide in its broadest part. It is irregular in outline and almost entirely covered with rocky hills and low mountains reaching an altitude of nearly 2,000 feet above the sea. The shore line is mainly rocky and precipitous in places fronted by high cliffs. The northern quarter of the island is nearly separated from the rest by two narrow indentations formed by the sea. On the west side, near the southern end, is a small bay with a small mangrove swamp on the flat near its head. A narrow valley extends inland from this flat and forms part of a pass across the island, extending between low rounded hills and mesas. The southern end of the island is separated from the opposite point of the peninsula by San Lorenzo Channel, a shallow strait about 3½ miles broad and 5 fathoms deep. The geological formation of the island appears identical with that on the nearest point of the mainland, and the shallow water separating them indicates the existence, at no remote period, of a former land connection between the two.

Espiritu Santo has no fresh water except in natural tanks after rains, but at the time of our visit small houses had been built on the shore of the bay mentioned above by a company organized at La Paz and apparently successful experiments were being made in the artificial propagation of pearl oysters. The valley leading back from the head of the bay and favorable

places elsewhere on lower slopes had many scattered Arid Tropical and Lower Sonoran shrubs and other plants, but the upper hill slopes are rocky and extremely barren.

The vegetation of the island is practically identical with that of the adjacent mainland and mostly Arid Tropical in character with a mixture of giant and other cactuses. Among the prominent species noted were *Tapirira edulis*, *Elaphrium microphyllum*, *Forchammeria watsoni*, *Bourreria sonorae*, *Jatropha canescens*, *Pedilanthus macrocarpus*, *Lemaireocereus gummosus*, *L. thurberi*, *Pachycereus calvus*, several opuntias, and *Pereskiopsis brandegeei*.

The birds were some of the more common species of the adjacent part of the peninsula, including the fish hawk, the sparrow hawk, the San Lucas and cape woodpeckers (*Dryobates* and *Centurus*), the raven, canyon and rock wrens, Gambel shrike, cape verdin, and western mockingbird.

This island has a larger variety of mammal life than many of the other islands along the coast, probably owing to its more recent connection with the mainland. The five species and subspecies occurring here are peculiar to this area but closely related to forms common on the adjacent mainland. The jack rabbit of Espiritu Santo is unquestionably derived from the *Lepus californicus* stock of the peninsula; through isolation it has developed into an extraordinary black animal, specifically distinct. The other mammals of the island, including representatives of *Perognathus*, *Ammospermophilus*, *Neotoma*, *Peromyscus*, and *Bassariscus*, show no such striking differences from their mainland relatives.

San Jose Island.

San Jose is located immediately north of La Paz Bay and is separated from the mainland by a channel from 3 to 5 miles broad. It is over 16 miles long northwest by southeast and about 7 miles in greatest breadth. The island is covered with hills and low mountains reaching an altitude of over 2,000 feet. The shore line is bold and rocky, and the mountain slopes rise from the sea except on the southern end, where the hills become low and the coast is mainly bordered by a sandy beach. A lagoon lies back of the beach near the southwestern point and contains a mangrove-covered island. A single small spring is known in the interior and fresh water also exists at the head of the bay near the lagoon at the southwestern point. Sand beaches occur at several points along the west coast and a ranch is located on the shore near the middle of this side of the island. The vegetation of San Jose is practically the same as that of the adjacent mainland but averages rather smaller. It is most plentiful in the canyons and other drainage ways, the rocky higher slopes being extremely barren.

Over 40 species of land and water birds are known from this island. The water birds include all the species known from this part of the gulf. The land birds are the same as those of the adjacent mainland. The mangrove island in the lagoon at the southwestern point is a breeding place for the San Lucas blue heron and other water birds; and Cayo Island, just offshore from the southwestern point, is a breeding place for Craveri's murrelets. The mammal fauna of San Jose is more extensive than on any other island off the coast of Lower California except Cedros. It includes the peninsula mule deer (*Odocioleus hemionus peninsulae*), the San Jose brush rabbit (*Sylvilagus mansuetus*), a kangaroo rat (*Dipodomys insularis*), a pocket mouse (*Perognathus spinatus bryanti*), a wood rat (*Neotoma intermedia pallida*), and a bassarisk (*Bassariscus astutus insulicola*). The deer is supposed to be the same as that of the adjacent mainland. The other mammals are all peculiar to the island, but are close relatives of forms occurring on the adjacent shore.

Carmen Island.

This large island lies about 125 miles northwesterly up the coast from La Paz and about 5 miles offshore. It is long and narrow except at the northern end, where it broadens, and a large spurlike point extends at an angle to the southeast, inclosing Salinas Bay. The island is about 17 miles long in a northeasterly by southwesterly direction and over 5 miles broad at the widest part near the north end. A range of low peaks from 500 to 1,500 feet high extends the entire length and the shore line is mainly rocky and precipitous, but at the heads of several small bays there are sandy beaches with the lower slopes of the hills and mountains rising behind

Fig. 1.—El Tule Arroyo, a clear stream in canyon at junction of Sierra de las Tinajas and Sierra Juarez. (Photograph by Dr. W. J. Mixter.

Fig. 2.—Tinaja Santa Clara in Overhanging Cave, Mountains on the west side of the Yuzcaldo Desert. The tinaja proved fatal to the teamster of a canyon flatteth (Lava Tail

FIG. 1.—Rattlesnake Harbor, on southeast shore of Angel de la Guarda Island. Most of the shore line is rocky and precipitous. (Photograph by L. C. Decius.)

FIG. 2.—Sea Elephant Cove, on northwestern shore of Guadalupe Island. Note the heads of sea elephants in the water. (Photograph by F. E. Norton.)

them. In the angle formed by the projection on the eastern side of the island near its northern end lies Salinas Bay, at the head of which is the noted salt lagoon, where a good quality of table salt has been mined for many years. Here a small village is located, inhabited by people who work the salt deposits. Fresh water is found here, and about halfway from Salinas Bay to the southern end of the island on the east coast is a small stream of fresh water.

Carmen Island has a rather plentiful Arid Tropical flora consisting almost entirely of the species common to the adjacent shore of the peninsula, including numerous large cactuses belonging to several genera in addition to the great viznaga (*Echinocactus digueti*) peculiar to the gulf islands.

The birds are the common species of land and water fowl of the gulf and its adjacent shores.

Only three mammals, all small rodents, are known from the island, all of which are forms peculiar to it but close relatives of mainland species. These include a *Perognathus*, a *Peromyscus*, and a *Neotoma*.

Angel de la Guarda Island.

This is the largest island on the coast of Lower California, having a length of about 40 miles and an extreme width of 10 miles. It lies parallel to the coast in a northwestern by southeastern direction, from 10 to 15 miles offshore, well up in the northern part of the gulf and nearly opposite Tiburon Island of the Sonoran coast. The island is unusually high and mountainous, with a rocky ridge extending its entire length and reaching altitudes from 3,000 to 4,000 feet. The mountain ridge is highest at the two ends and separated by a comparatively low depression or pass in the middle. The shores are mainly very rocky and precipitous, the western coast being inaccessible, but there are several landing places on the eastern side and a low area and a small bay at the northern end. The island is extremely rocky and barren, but considerable scattered vegetation of the same species found on the adjacent mainland of the peninsula grows there, including many cactuses. This island is reported to abound in the large black chuckwalla (*Sauromalus*) and rattlesnakes. A few of the common birds of the coast occur here, and two species of mammals have been found—a mouse (*Peromyscus guardia*) and a wood rat (*Neotoma insularis*).

A few tinajas or natural water tanks are reported to exist on this island but no living water.

Guadalupe Island.

Guadalupe is one of the largest and most notable islands lying off the coast of Lower California. It is situated 135 miles southwesterly from Point San Antonio, south of the mouth of Rosario River. It is roughly wedge-shaped and is nearly 22 miles long by 3 to 6 miles across, the broadest part lying to the north. The island forms a high unbroken volcanic ridge, highest in the northern part, where it reaches an altitude of over 4,500 feet above the sea. It is entirely surrounded by very deep water, which, 4 miles from the northern end, reaches a depth of 1,400 fathoms, and about the same distance from the southern extremity a depth of over 1,100 fathoms. Between the island and the mainland to the east is a great valleylike depression of the sea bottom having a depth of over 2,000 fathoms. This shows that the summit of Guadalupe is the crest of a gigantic mountain ridge rising over 16,500 feet above its base level on the sea bottom with only a little more than one-quarter of its height appearing above the surface of the sea. On the west the ridge of the island slopes rapidly toward the sea, ending in the high cliffs. On this slope two great canyons lead down to the sea, separated by a barren hill of reddish rock. On the northern part of the island the ridge is very sharp and descends precipitously on the west, but slopes less rapidly on the east. There are several small elevated plateaus on this end of the island. The southern part is lower with more gradual descent and ends less abruptly. The surface of the island is covered with rough fragments of volcanic rock from the size of pebbles to huge, ragged, outcropping bowlders. The shore line is formed of perpendicular cliffs, which are extremely rough and precipitous, with many volcanic caves and holes which were formerly the favorable resorts of the Guadalupe fur seal.

There are several springs on the northern plateaus but apparently no fresh water on the southern half of the island. Wood and water may be found at a small cove near the northeastern end.

Guadalupe has the same wet and dry seasons as the California coast. Owing to its situation in the midst of cool ocean currents and the prevalence of the northwesterly winds, it is much cooler than any part of the coast of Lower California at the same altitudes. The winters are especially cool, owing to the cold sea winds and prevalence of fogs; the summers are much dryer and are comparatively very hot. Dense fogs are more abundant in winter but prevail also about higher parts of the island throughout most of the year. Dr. Edward Palmer reports that in December, 1874, ice formed an inch thick on the middle of the island accompanied by 2 inches of snow and hail and followed by five days of cold rain.[1]

During the winter of 1885–86 W. E. Bryant spent several months on the northern plateaus and experienced many cold rains and some frosts. During May and June, 1906, W. W. Brown explored the island and noticed that nearly every time there was a gale from the northwest it was accompanied by heavy fogs. He found the temperature so low that it was necessary to keep a roaring fire in camp, especially at night. For 10 days at a time the sun was hidden and everything was so saturated with moisture that it was difficult to preserve specimens. During the gales, when collecting in the open was impossible, Brown found that inside the cypress forest on the high tableland hardly a breath of air would be stirring so perfect was the protection of the heavy growth of these trees.

At the time of his visit Brown found that the entire plateau of the southern half of the island was a sunburned waste with hardly a leaf of living verdure, but the higher and northern parts were more fertile and less dependent on rainfall, owing to the constant heavy fogs enveloping it. He discovered that the pines growing on the northern ridge of the island gave fine illustrations of the ability of trees to condense moisture from the air. These trees are on the summit of a precipice nearly 3,000 feet high facing the sea on the western side. When a strong wind brought in a fog, the ground under the pines streamed with water, which ran down the tree trunks, while the open ground some distance away was scarcely dampened. He adds that long ago, when the entire northwestern part of the island was covered with dense forest, the condensation must have been considerable, thus producing numerous springs and greatly benefiting the vegetation. Watson states that the low southern end of the island is warm and sunny, while the high northern end is covered by cold fog.[2]

Vegetation of Guadalupe.—The flora of Guadalupe is more closely related to that of California than to that of Lower California. More than 145 species of plants are known from the island, of which at least 29 are peculiar to it. The lower southern end of the island is much warmer, drier, and more barren than the northern and entirely lacks trees. Watson (op. cit.) states that vegetation in the warm eastern canyons and on the southern end is two months ahead of the cold north and west parts. The higher northern end has scattered tracts of pines, cypresses, oaks, and palms.

Unfortunately, the presence on Guadalupe of thousands of goats, which increase almost unchecked, has proved disastrous to the vegetation. Brown estimated that there were from 6,000 to 8,000 goats at the time of his visit in 1906, and states that the few plants that have escaped them are growing on perpendicular basaltic cliffs or are old trees with bark too hard and woody to eat. He did not find any young trees growing in the cypress, palm, and pine woods. The goats and house mice, which have also been introduced by man, eat the seeds as they fall, thus preventing the trees from reproducing themselves, and if present conditions continue the trees must become extinct. He noted that kids only a few months old were able to eat the hard palm seeds. Two species of trees are already extinct.

At the northern end of the island Brown found the following conditions: A fast-decaying pine forest was growing along the narrow crest of the mountain at an altitude of about 3,000 feet and in some places down its almost perpendicular western slope. The ground was strewn with dead trees, goat trails winding among them in all directions. On the highest part of the island, north of Mount Augusta, a large cypress forest covers an area of about 3 square miles on the western slope, ending abruptly on the east at the crest of the ridge. Hundreds of cypress trees show the marks of goats' teeth and many were dead or dying. No living junipers

[1] Proc. Amer. Acad. Arts and Sciences, XI, pp. 112-121, 1875 [1876].

[2] Idem, pp. 105–112.

were seen, but numerous dead stumps showed where a grove once existed. Far down on the northwestern slope is a large grove of cabbage palms (*Erythea edulis*), and a small grove of the same exists near Steamer Point on the west shore. In the large palm grove mentioned above are some fine oak trees 30 to 65 feet high, and east of the cabins on the plateau under a cliff several oaks were growing, but they were stunted and low branching. In May and June vegetation consisted generally of wild oats and foxtail grass, but with a profusion of a species of malva about old corrals. In the main cypress forest, on the high tableland, were numerous dead stumps of some species of shrub probably now extinct on the island.

The original vegetation of Guadalupe has held its own only along the faces of bluffs and precipices which are inaccessible to the goats.

Birds of Guadalupe.—In 1875 the late Dr. Edward Palmer visited Guadalupe and was the first to make known its interesting fauna and flora. From his collection the birds peculiar to the island were first described. Several other American naturalists have since visited the island and studied its bird life, the more notable of these being W. E. Bryant, in 1884 and 1885–86; A. W. Anthony, several times between 1892–1897; W. W. Brown, in the spring of 1906; and several expeditions from the California Academy of Sciences at different times.

Forty-two species and subspecies of birds are known from Guadalupe, of which eight are endemic. Since the partial destruction of vegetation by goats and the increasing great abundance of domestic cats which were introduced there by goat herders, two species, *Pipilo consobrinus* and *Thryomanes brevicaudus*, have disappeared. The Guadalupe caracara (*Polyborus lutosus*) has also become extinct. The last-named species was probably exterminated by poison put out by goat herders owing to their depredations among the newly born kids. Mr Brown found wings and feathers of juncos, rock wrens, and Guadalupe flickers, showing where these birds had been killed by cats. He adds that the mortality among the petrels and shearwaters from this source must be great on the northern ridge where they breed, for he saw hundreds of of their wings strewn about.

Mammals of Guadalupe.—There are no indigenous land mammals on Guadalupe. Domestic goats, cats, and house mice have been introduced and have become so destructive to the plant and bird life that the original fauna and flora appear to be doomed to almost complete destruction within a limited period. Mr. C. H. Townsend states that many of the goats perish each year for lack of water during the dry season, and as the vegetation decreases the available water supply will undoubtedly decrease with it.

The shores of this island were once favorite resorts for great numbers of Guadalupe fur seal (*Arctocephalus townsendi*), which is now supposed to be almost if not quite extinct. A small herd of sea elephants, the last representatives of the once enormous numbers of these animals, still remains on the western side of the island. (See Pl. 25, Fig. 2). Sea otters were once abundant about these shores, but they are now gone forever. Sea lions and harbor seals still frequent its shores in small numbers.

Life zones of the island.—We lack the necessary detailed observations on the vertical distribution of the plant and animal life of this island to properly define its life zones. For this reason they can be located only in the most general way. The basal slopes of Guadalupe and practically all of the eastern and southern sides below the higher parts of the summit are Upper Sonoran. The summit as well as most of the northern and northwestern slopes are within the Transition zone. *Colaptes cafer rufipileus*, *Junco insularis*, *Thryomanes brevicaudus*, and *Sitta canadensis* appear to be Transition zone species here. The main trees characterizing this zone on Guadalupe are *Pinus radiata* and *Cupressus guadalupensis*.

CLIMATE.

The climate of Lower California as a whole is extremely hot and dry. Much brilliantly sunny weather with scanty and uncertain rainfall over all of the peninsula results in the prevalence of marked desert conditions. There are, however, considerable local climatic variations according to the situation in relation to latitude, altitude, mountain ranges, and to the east and west coasts. The contrast is most marked between the excessive summer heat on the low

desert near the head of the Gulf of California and the cool temperatures on the highlands of the San Pedro Martir Mountains. The greatest annual range of temperature is on the desert near the delta of the Colorado and amounts to more than 100° F.

In winter sharp frosts occur on these deserts and from 3 to 4 feet of snow, with severe freezing temperatures on tops of the highest mountains. The daily extremes of temperature on the deserts, especially on the east side, are often considerable, the days being extremely hot and the nights comparatively cool. Immediately along the coast on both shores the daily variations are much less than they are farther inland. Throughout the peninsula the healthfulness of the climate is unexcelled. So far as health and comfort are concerned, I fully agree with Dr. Eisen in his statement that the "Cape Region of Baja California is one of the very few places where the various conditions of temperature, moisture, and other climatic conditions are almost perfect."

Much the larger part of the peninsula lies within climatic conditions which characterize the Lower Sonoran life zone, changing to Arid Tropical conditions in the southern third, and to Upper Sonoran and Transition on the mountains. The climatic conditions of the northern parts are similar to those which prevail in the immediately adjoining sections of southern California.

Winds.

Winds have a strong influence on climatic conditions in some parts of the peninsula, especially on the western side. Northwesterly winds blow almost continuously along the entire length of the west coast from March to October, and during this period fine weather with but little rain prevails. Owing to the cool northerly ocean current which bathes all the west coast, the northwest winds coming across the sea have their temperature reduced and, while everywhere more or less moist, are here frequently laden with fog which sweeps inland and at times spreads over the entire west slope to the sides of the mountainous backbone of the interior. From November to February the wind varies on the west coast from southeast to southwest, with occasional southeast gales accompanied by heavy rains. In the cape district these heavy winter rains, which are described below, are called "equipatos." In December and January heavy northers, lasting from one to three days, sometimes occur, mainly in the cape district and on the west coast.

The winds of the eastern or gulf shore are much more unsettled and irregular than on the west shore. In spring and summer northwest winds are common, some southeasterly winds occur, and light breezes and calms are prevalent. In winter, northwesterly gales occur in the gulf. At the end of the tropical rainy season on the mainland, in autumn, fierce southerly gales of several days' duration occur in the southern and middle parts of the gulf, and sometimes increase to destructive hurricanes which sweep the gulf and the lowlands of both its coasts. They are known as "El Cardonazo," and occur at intervals of several years, being accompanied by thunder, lightning, and torrential rains. An early record of one of these tempests is given by Venegas, who tells us that "in the autumn of 1717 a terrible hurricane arose and extended all over Lower California and the gulf, accompanied by violent rains, which swept everything before it. The church and Padre Ugarte's house (near Mulege) were leveled to the ground and he saved his life by taking refuge under a rock, where he was exposed to the severity of the weather for 24 hours. The channel for carrying water was choked and the sluice at San Xavier carried away. The cultivated land, both here and at Mulege, was completely ruined and covered with stones."[1] In September, 1896, one of these hurricanes, accompanied by floods of rain, did great damage in the lowlands of Sinaloa.

On the night of October 4, 1817, a terrific hurricane with heavy rain caused a flood at San Jose del Cabo, destroying many houses and drowning 45 persons. On September 17, 1918, a characteristic autumnal hurricane visited the northwest coast of Mexico and the southern gulf coast of Lower California. Two United States Shipping Board vessels on their first voyage were reported sunk off the southern end of the peninsula, and other ships were badly battered.

[1] Noticia de la California, II, p. 310, 1757.

The town of La Paz was partly wrecked, several people were killed, and the equipment of the United States Naval Station at Pichilinque, in La Paz Bay, was seriously injured. The fall and winter hurricanes of the gulf coast carry with them such floods of rain that they are difficult to classify and some of them are described under the account of the rainfall. These fall and winter storms render navigation of the gulf at these seasons rather hazardous, although in the main the weather is pleasant.

Rain and Snow.

Owing to its great length and to its geographical relations to the continental mainland, Lower California has two definite rainy seasons, both of which at times include the entire peninsula. The first of these is part of the tropical summer rainy season which regularly occurs on the west coast of Mexico as far north as northern Sinaloa, the border of which extends across the gulf to Lower California and is specially marked in the southern part of the cape district.

The second rainy season of the peninsula is a part of the winter rains of the north Pacific coast, which extend southward from California and at times even reach the vicinity of Cape San Lucas. As the peninsula occupies the borderland between the main areas covered by both these rainy seasons, it is strongly affected by any departure from normal conditions in either of them, and a scanty rainy season in either direction usually means an entire absence of rain for the corresponding period on the peninsula.

No year passes without some rainfall in some part of Lower California and rain falls practically every year on the high mountains of the northern and southern ends. Rain is usual every year also in some parts of the lowlands, but at times unbroken droughts continue over the low areas of a large part of the peninsula for periods of from two to more than five consecutive years. During such long droughts the smaller herbage disappears, the cactuses and desert shrubs show little vegetative activity, and most of the cattle and the native mammals on the ranges in the dry areas die. Long periods of excessive drought were recorded in the chronicles of the early Spanish missionaries, who told of the suffering thus entailed on themselves as well as on the Indian population. They are the main cause of the present scanty population of the peninsula and are responsible for the many abandoned ranches and unsuccessful attempts at colonization throughout its extent. These periods of excessive droughts are followed by years of torrential rains which flood the country and temporarily change the dry and sandy watercourses into booming streams.

The areas of least rainfall in the peninsula are the desert northeastern section, Vizcaino Desert, and the lowlands surrounding La Paz Bay.[1] The areas of greatest precipitation are the San Pedro Martir Mountains in the north and the Laguna Mountains in the south. Precipitation is greatest along the highest mountain slopes and diminishes along the basal slopes to the general average of the surrounding lowlands.

But few accurate records of the annual precipitation are available for any part of Lower California. Conditions are so similar in the lowlands of the northern end of the peninsula and adjacent parts of southern California that it is evident the precipitation must be practically the same for a considerable distance on both sides of the border. The rainfall of San Diego averages about 9.4 inches yearly, which is approximately that of the coast of the peninsula as far down as Ensenada, beyond which it rapidly decreases. The rainfall at Salton, on the southern border of the Colorado Desert, averages about 2.5 inches and probably is about the same on the lowlands of the peninsula south to beyond San Felipe Bay.

Conditions unlike those in the north and the lack of accurate observations render estimates of the rainfall in the middle and southern parts of the peninsula of little value, except to give a general indication of the relative humidity. Dr. Eisen has estimated that the average annual rainfall at La Paz is less than 2 inches, at Miraflores about 20 inches, at San Jose del Cabo less

[1] In the discussion, a few years ago, of the supposed change that might occur on the Colorado Desert from the humidity due to evaporation from the newly flooded Salton Basin, those who advanced the theory of probable climatic change from that source should have considered conditions 100 miles farther south, where the humidity due to evaporation from the vastly greater area of the Gulf of California has no appreciable effect in modifying the extreme desert conditions of the bordering country either in Sonora on the east or in the area between the gulf and the east base of the lofty San Pedro Martir Mountains in Lower California.

than 12 inches, along the coast near Cape San Lucas not over 5 inches, and in the Sierra de la Laguna about 30 inches.[1]

The summer rainy season of Lower California, as already stated, is most marked in the cape district. It begins there somewhat later than on the opposite Mexican mainland coast and ends earlier, usually lasting from July until October or November, September being the wettest month. Most of our information concerning these rains in this district is from Dr. Eisen.[2] He found that the earliest summer rains fall on the divide at the north end of San Jose Valley, just north of Miraflores. Rains begin at Miraflores long before they do at San Jose del Cabo, and sometimes fall even at Santa Anita several weeks before they reach San Jose, although the latter is only 9 miles farther down the valley. The rainfall along the mountains bordering the gulf shore southeast of La Paz is less than among the mountains farther inland. The rains are more abundant and regular in the Sierra Victoria, the mountainous area between La Paz and the cape, than elsewhere in the southern half of the peninsula, and next to this are most copious on the high mountains immediately bordering the gulf coast for some distance north of La Paz Bay.

During the summer rains thunder may be heard and rain seen to fall daily for weeks in the mountains of the cape district without a drop falling on the surrounding plains. Eisen states also that the rainfall is heaviest west of the crest of the Sierra Victoria, though the steeper slope there causes it to run off more quickly and so its influence on the vegetation is less evident than on the more gently sloping east side. He has so well stated the character and effect of the summer rains on the lowlands of southern Lower California that his account is worth quoting. He says: "They are most capricious as regards time and locality, and while one place may be deluged another close by may never receive a drop. This is frequently seen in passing through the country. In some places I found flowers and grass in abundance, and animal life was represented by thousands of snails crawling on the bushes. A few yards or a mile away everything was barren, dry, and dead, no rain having fallen there for years. When the water comes down it generally comes in torrents, washing everything before it. This torrential rain, which may amount in a single shower to 3 or 4 inches, has thus rarely the opportunity to sink deep in the soil. On the contrary, it carries everything before it, and leaves its trace behind in the formation of the precipitous walls of the canyons and in great washouts." [3] In October, 1905, Goldman found the vicinity of the Tinaja Santa Clara on the Vizcaino Desert very dry and no sign of rain that year, but a few miles to the eastward near the Cerro de Tecolote sufficient rain had fallen so that desert trees and bushes were in full foliage and the ground was covered with green grass and flowering plants.

The tropical summer rains commonly extend north along the elevated interior to the middle of the peninsula and less frequently to the adjacent coasts. They are more and more irregular up the west coast as far as San Quintin and along the east coast to the extreme northern border about the Cocopah Mountains. These summer rains are always more common along the mountainous backbone of the peninsula than on the coasts, and are of more frequent occurrence on the high summits of the San Pedro Martir Mountains than elsewhere in the north. Occasionally the outskirts of the area covered by the summer tropical rains extend as far north as the southern end of the Sierra Nevada in California, where they are manifested by sporadic thunderstorms.

In 1905 we saw the first manifestations of the approach of these rains in the north. Up to June 11 the sky had been absolutely cloudless, but on that date cumulus clouds formed over the summits of the San Pedro Martir Mountains and then spread northward over the Sierra Juarez and disappeared late in the afternoon. This was repeated the following day and the natives told us that these clouds indicated the approach of the summer rains, although it was several weeks later before rain actually fell.

The day we reached Vallecitos, on top of the San Pedro Martir Mountains, July 12, 1915, there were several brisk thunder showers accompanied by hail. Mr. E. W. Funcke writes that from July 2 to 6, 1906, heavy thunderstorms prevailed in these mountains and from then until the end of August rains were plentiful throughout this section. He adds that summer rains

[1] Calif. Acad. Sci., V, p. 742, 1895.
[2] Proc. Calif. Acad. Sci., V, pp. 741–745, 1895.
[3] Bull. Amer. Geog. Soc., XXXII, No. 5, pp. 405–406, 1900.

occur nearly every year on the Cocopah or other desert mountains in this section and thence southward along the gulf side. These rains are commonly in the form of cloudbursts, usually in July, August, and September. They may occur any year but are irregular and may not appear for several successive years. Such cloudbursts occur at times on the desert plains as well as in the mountains between the Sierra Juarez, the San Pedro Martir Mountains, and the gulf. Mr. Funcke reports a heavy cloudburst at Calexico, just at the northern border of the peninsula, on August 16, 1909, when nearly 2 inches of rain fell in two hours. The summer of 1910 rains began on the desert south of Calexico, July 13 and 14, and were followed later in the season by heavy cloudbursts.

On August 21, 1884, rain fell for more than 48 hours at San Ignacio, and water ran for several days in the arroyo. On June 30, 1911, a general rain occurred in the district about Calmalli, after which unbroken dry weather prevailed until October 4, when a heavy storm covered the middle region of the peninsula from about Calmalli to beyond San Ignacio. Shortly before 11 p. m. on the 3d of October a light rain fell at San Ignacio, which continued, accompanied by a strong gale from the north during the early hours of the 4th. At the same time an extremely heavy rain fell in the Santa Lucia and other mountains to the east and on the table-land 20 to 30 miles to the east and north, continuing until about noon on the 4th. Most of the water drained into the San Ignacio Arroyo, down which it ran with great force, striking San Ignacio about 11 a. m. The front of this flood was reported to be from 12 to 15 feet high. Twenty-three persons were reported drowned, 39 buildings destroyed, and many others badly injured. All the gardens and small fields in the valley were washed away, including thousands of date palm trees. At Calmalli it only rained about an hour on the morning of the 4th, accompanied by strong north winds. This rain extended about 35 miles east of the last-named place and a little to the north. Considerable rain fell along the gulf coast east of Calmalli, and a heavy gale raged at the same time over the gulf, destroying much property at Santa Rosalia, on the west side of the gulf, and at Guaymas and Mazatlan, on the east side, thus indicating its extended character. Neither this storm nor the one of June 30 reached as far west as the Pacific coast. On August 25, 1912, a light shower fell at Calmalli, the first rain since the preceding March.

Besides the summer rains, as already mentioned, the peninsula also has a winter rainy season of the same origin as the winter rains of California and coincident with them. These winter rains are less regular than in California, but at times extend southward to include the entire length of the peninsula, though more frequent and abundant in the northwestern parts, especially in the Sierra Juarez and San Pedro Martir Mountains and thence to the Pacific coast. On the desert east of these mountains the winter rains are reported to be very irregular and commonly to last only a few hours except when they appear as the torrents accompanying the widely spread storms which sometimes occur during this season. Some years no winter rains fall. I have been informed that during the winter of 1908–9 in the northeastern part of the peninsula there were but four or five rainy days, while in the season of 1909–10 no rain fell. The winter precipitation on the summits of the Sierra Juarez and San Pedro Martir Mountains is mainly in the form of snow which some seasons, according to A. W. Anthony, falls to a depth of 6 feet or more on the higher parts and lies on the north slopes of the summits till late in May.

Snow falls every winter from the northern border south along the Sierra Juarez and San Pedro Martir Mountains to Rosarito Ranch, Matomi, and on San Juan de Dios Mountain, but rarely or never farther south than the latter point. On October 12, 1908, the top of the San Pedro Martir Mountains was covered with snow and it falls on these mountains between October and March, the 20th of March being about the latest date. The summits of these mountains are never covered with snow during the entire winter but usually only for periods of from two to four weeks. In midwinter snow falls far below the lower border of the pine timber. Anthony writes that it falls down to about 2,500 feet above sea level on the west base of the mountains and it sometimes reaches as far as Valladares. November 17, 1902, Edmund Heller was driven out of the Sierra Juarez by a snow storm. Cattlemen who occupy the range on these mountains in summer usually drive cattle up to the higher levels early in April and down

to the lowlands on the west side early in October. Mr. Funcke writes that he has never seen snow on the Cocopahs nor on any of the desert mountains between the San Pedro Martir Range and the gulf.

Although winter rains are most regular in the northern half of Lower California, yet they sometimes extend the entire length of the peninsula and fall in great abundance in the cape district. They are most abundant throughout the peninsula on the western slope. In the cape district they often accompany gales from the southeast and are called "equipatos." The people there say they are sometimes entirely lacking for several years in succession, but often occur in the form of prolonged storms, sometimes extending over a period of from 12 to 15 days. At such times the entire country becomes so boggy that all overland travel is suspended. We experienced these conditions after the rain storm of December 10 and 11, 1905, which flooded the Llano de Yrais, opposite Magdalena Bay, where we traveled for nearly two days through broad shallow ponds and many swiftly flowing streams in the washes. Another day of rain would have made the country impassable. It was a curious sight to see miles of giant cactuses and other characteristic desert plants standing in the midst of broad half-submerged expanses. The winter of 1904–5 was one of extremely heavy rains throughout the peninsula. One storm continued for about two weeks throughout the cape district and rendered travel temporarily impossible. The winter of 1905–6 several rains occurred in this region in November and December and again in January and February. Although sharp frosts are common on the Sierra de la Laguna in winter, yet the residents of that region report that snow never falls on these mountains.

The following fragmentary records for rainfall by inches in different localities give an indication as to the precipitation in the lowlands of certain parts of the peninsula:

Records of rainfall, by inches, in certain parts of Lower California.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Santa Rosalia:												
1898	×	×	×	×	×	×	×	×	×	×	×	0.53
1905	×	1.44	1.40	0.31	0	×	0	0.51	0.20	0.14	×	.80
1906	0.39	.51	T.	×	0	0	0.18	.04	×	×	0	×
1907	1.18	0	T.	0	0	0	×	8.18	×	×	×	×
1908	×	×	×	×	×	×	×	.08	×	×	×	×
1909	×	×	×	×	0	×	1.26	×	1.42	0	×	×
1910	×	×	0	×	×	×	×	×	×	×	×	×
1913	×	×	×	×	×	0	×	×	×	×	×	×
1914	T.	T.	×	×	0	×	×	×	×	×	×	×
La Paz:												
1906	×	×	×	×	×	×	0	1.97	.24	1.02	0	×
1907	.71	0	0	0	0	0	.87	4.96	×	3.82	×	×
1908	0	.15	×	0	0	×	×	T.	.99	×	×	×
1909	×	×	×	×	0	0.72	×	1.01	T.	0	0	2.07
1910	0	0	0	0	0	0	3.06	2.45	×	.05	0	0
1911	1.20	×	.05	0	0	1.11	.54	.59	4.00	×	×	×
1917	×	×	×	×	×	×	×	×	×	×	0	0
1918	0											

× Indicates no record. T Indicates a trace.

Ensenada.—1888, season's rainfall (from fall of 1887) to March 31, 12.06; 1894 to 1911, seasonal average, 9.74; 1919, season's rainfall to March 14, 8.10.

Ojos Negros (ranch).—1909–1911, seasonal average, 9.16.

San Quintin.—1908–1911, seasonal average, 5.24.

Fog and Dew.

Fogs in Lower California are limited mainly to the west slope within the influence of the northwest winds. They occur at all seasons, but are more prevalent during the summer months. As in southern California, they generally set in at night and clear late in the morning, the rest of the day being bright and pleasant. Fogs are most common from the northern border to San Quin-

tin and are only a little less common thence south to Cedros Island. From Cedros Island to Cape San Lucas fogs are much less frequent than to the northward and they clear away earlier in the morning. They are rather common in fall and winter at Magdalena Bay and on the adjacent coast. All along the west coast the fogs sweep in over the lowlands and near Ensenada up to over 4,000 feet altitude and in the middle of the peninsula to from 2,000 to 3,000 feet. June 1, 1905, San Rafael Valley, east of Ensenada, was hidden in fog which extended up on the west base of the Sierra Juarez. Fogs were reported to be common here at this season. At daybreak, September 18, 1905, a heavy fog covered all the coastal plains and low mountains up to the tops of the granite mountains back of our camp at Yubay, in the middle of the peninsula. The 1st of November, 1905, at La Purisima a heavy rain was followed by a dense fog which covered the coast plain and interior mesas up to the high interior mountains. Valleys shut off from the coast by a low mountain, or ridge, like that at San Fernando, even though draining into the Pacific, are usually cut off from the fogs and most of the dews so common in places open to sea winds. The middle of October, 1905, fog drifted down from the north each night over the Vizcaino Desert.

Fogs are much more prevalent about Cedros Island than on the mainland and still more so at Guadalupe Island. The abundant moisture provided by the fogs has great influence in producing the luxuriant desert vegetation on parts of the west slope. The amount of moisture which may be contributed from fogs to vegetation is well illustrated by the observations of W. W. Brown, the 1st of May, 1909, on Guadalupe Island.[1] Fogs were very prevalent there, and in the morning the ground about the bases of the pines growing on the high slopes was streaming with water which had been condensed in the tree tops and ran down the trunks to the ground.

Copious dews are also common on the west slope of the peninsula and in the morning the vegetation is often dripping with moisture and the surface of the ground dampened as from a light shower. The blazing sun quickly dries up this surface moisture but not before the desert plants have had opportunity to appropriate some of it. A. W. Anthony informs me that during the years he lived in the region west and south of the San Pedro Martir Mountains heavy dews were prevalent, especially in valleys near the coast, which made the nights chilly throughout the year. The prevalence of coast fogs along the lowlands bordering the west shore is shown by the abundance of orchilla and other epiphytic plants on the desert shrubs and small trees from near Magdalena Bay northward. Between La Paz and Cape San Lucas fogs sometimes hang about valleys and mountain slopes during, or at the end of, long-continued storms, but are rarely seen at other times.

Fogs and dews are of very rare occurrence on the east slope of the peninsula, where the high interior mountain ranges cut off the moist northwest winds which supply them on the west side. The water of the gulf is much warmer than that of the Pacific, and the gulf slope of the peninsula is much hotter and drier than the west side. We did not see a single fog or dew on the east slope during 1905–6.

Temperatures.

But little exact information is available concerning the temperatures in any part of Lower California. Freezing temperatures are known to occur in winter throughout the peninsula except in an extremely narrow belt immediately bordering the sea in the cape district and extending northward on the west coast to San Jorge and on the east coast to beyond Santa Rosalia. Frosts are unusual anywhere in the immediate vicinity of the shore. Within a narrow coastal belt, rarely over 3 miles wide, from the northern border to opposite Cedros Island the temperatures are much like those at San Diego, Calif., which range from 32° F. in winter to 101° F. in summer. From Cedros Island southward to beyond Magdalena Bay the coast belt is warmer in summer than to the north of that island, but still not so warm as the interior. This entire coast belt owes its coolness to the northwest winds and has the most agreeable summer climate of any part of the peninsula lowlands. Inland on the west slope the summer temperatures are

[1] Condor X, p. 102, 1908.

much higher than near the Pacific coast and not uncommonly go well above 100° F. At La Paz winter temperatures are said to range from 50° to 74° and summer temperatures from 80° to 94°.

The hottest part of the peninsula is the northeastern section, between the Lower Colorado River and head of the gulf on the east and the Sierra del Pinal and San Pedro Martir Mountains on the west. This area forms the southern end of the Colorado Desert and shares its extreme summer temperatures. Observations for several years at Salton, on the Colorado Desert not far north of the border, show extremes ranging from 18° in winter to 128° F. in summer, and a closely similar range undoubtedly occurs throughout the lowlands of the adjacent area south of the border.

The northern half of the east coast of the peninsula lies for months under the fierce heat of an unclouded sun, and the surface waters of the gulf become so warm that they help maintain the high temperatures, thus making this throughout the summer one of the hottest and most desert parts of the continent.

A considerable contrast exists between the temperatures both in summer and winter at opposite points on the two coasts. The difference is most marked near the northern border and becomes much less in the southern half of the peninsula. Southward the temperatures of the east coast become less excessive in summer until at San Jose del Cabo, according to Dr. Eisen, the maximum temperature rarely exceeds 90° F. On the west coast the summer temperatures increase southward but are always less than at opposite points on the east shore.

Arid tropical or semitropical conditions prevail along the coast lowlands of the east side from Cape San Lucas north to near the middle of the peninsula and on the west side north at least to San Jorge beyond Magdalena Bay and to San Ignacio Valley in the interior. Summer temperatures, as usual, decrease with increased altitude on the mountains and are cool and pleasant on the summits of the higher ranges such as the Sierra Juarez and San Pedro Martir Ranges in the north and the Sierra de la Laguna of the Cape District.

The winter temperatures on the Sierra Juarez and San Pedro Martir Ranges are much lower than elsewhere in the peninsula, especially on the high uplands of the San Pedro Martir Mountains, where a heavy cap of snow remains for some time. Occasionally throughout the summer light frosts occur in these northern mountains. Thus on June 4, 1905, we had a light frost at our camp near El Rayo Ranch, at 4,600 feet altitude, on the west side of the Sierra Juarez. Frosts were common in July at the same season in the high meadows on the San Pedro Martir Mountains. Sharp frosts occur in winter on the tops of the mountains all along the backbone of the peninsula to the Sierra de la Laguna and other southern mountains. Temperatures become so low at night, between December and March, on the Sierra de la Laguna south of La Paz that ice an inch thick is sometimes formed.

In the lowlands of the northern half of the peninsula frosts occur with considerable regularity and near the northeastern border and on elevated plains and valleys are often severe, the temperature sometimes falling to 18° or less on the Colorado Desert. Mr. A. W. Anthony informs me that killing frosts were rare at San Fernando, though the nights were usually cold there during the winter months. In the lowlands of the southern half of the peninsula frosts are more sporadic. At Comondu the people told us that frosts do not visit their valley every year but sometimes are of sufficient severity to kill the leaves of growing sugar cane. Light frosts were also reported to occur on the Llano de Yrais, a short distance inland from Magdalena Bay. They also occurred in the bottom of the valley a few miles above San Jose del Cabo while we were at Santa Anita, the middle of January, 1906. Dr. Eisen states that frosts occur in January and February at Miraflores and Caduano, sometimes killing back the vegetation, including the Palo de Arco (*Tecoma stans*).[1]

The temperatures on the coastal islands are closely like those on the adjacent mainland coast, but islands well offshore, like Cedros and Guadalupe, average much cooler, especially in summer. Sharp frosts occur in winter on the higher parts of Guadalupe.

[1] Proc. Calif. Acad.Sci., V. p. 738, 1895.

PLANT LIFE.

A report by E. A. Goldman on the more important plants collected during our explorations in Lower California furnishes detailed information concerning numerous species.[1] In addition notes and lists showing the zonal distribution of the species are given in the accompanying account of the life zones of the peninsula (pp. 117–132.)

The following notes contain general information concerning the characteristic features of the flora. The photographs throughout this report convey some idea of the region but do scant justice to the extraordinary appearance of landscapes overgrown for hundreds of miles with strange and grotesque vegetation. In many places these bizarre combinations are so unfamiliar in appearance that they might represent the flora of some former geological period.

The flora of Lower California appears to have been derived from three main sources, as follows:

1. From the mountain and foothill slopes of southern California, and extending thence down the peninsular backbone over the Juarez and San Pedro Martir Mountains and covering most of the area between these mountains and the Pacific coast.

2. From the deserts of northwestern Sonora, southern Arizona, and southeastern California. The plants derived from this last-named region form the dominant and most characteristic part of the general flora and cover approximately two-thirds of the total land area of the peninsula, extending its entire length and in some parts its entire breadth.

3. From the arid tropical lowlands, foothills, and low mountains of Sinaloa on the mainland coast of Mexico opposite the southern end of the peninsula. This part of the flora is mainly limited to the southern third of Lower California and is especially prominent in the cape district south of La Paz Bay. Many species range farther north, however, especially along the gulf coast, one copal reaching even to the delta of the Colorado. This tropical Mexican mainland element of the flora throughout its extent is intermingled with equally or more prominent representatives of the desert flora which comes in from the north. The presence in the southern end of Lower California of so considerable a number of arid tropical genera and species of plants common on the opposite mainland coast of Mexico appears to indicate a closer connection between the two areas than is shown by the reptile, bird, and mammal life.

Plants Derived from the Mountains and Foothills of Southern California.

The higher slopes of the Juarez and San Pedro Martir Mountains (above 4,500 feet), in the northern part of the peninsula, are capped with the only coniferous forest in Lower California, with the exception of an insignificant area of pinyons on the higher parts of the Victoria Mountains in the cape district and small areas of coniferous trees on the northern ends of both Cedros and Guadalupe Islands. The pine forest on the Juarez and San Pedro Martir Mountains forms a narrow belt for about 150 miles along the top of the range and contains the only merchantable timber in the peninsula. These pines form an open forest variable in character. It is often much scattered and the greater part of it is composed of pinyon or other scrubby trees of little or no commercial value.

It begins on the top of the Sierra Juarez near the California border and extends to within a few miles of San Matias Pass. It is absent on all the slopes of the pass below about 4,000 feet, but begins again immediately south of the pass, near San Matias Spring, and extends continuously thence south the entire length of the San Pedro Martir Mountains to their southern end at Matomi Canyon.

Jeffrey yellow pine (*Pinus ponderosa jeffreyi*) is the most important of the trees and forms the main part of the forest above about 4,800 feet on the Sierra Juarez and above 6,000 feet on the San Pedro Martir Mountains. (See Pl. 26, Fig. 1.) In the Sierra Juarez the Coulter pine (*Pinus coulteri*) is interningled with the Jeffrey pine and a smaller number of incense cedars also occur there. Among the Jeffrey pines on the San Pedro Martir Mountains there is a proportionately small number of sugar pines (*Pinus lambertiana*), white firs (*Abies concolor*) from about 7,500 feet to the summit, and of the incense cedar (*Libocedrus decurrens*) from about 6,500 feet

[1] Plant records of an expedition to Lower California, Contr. U. S. Nat. Herbarium, vol. 16, pt. 14, pp. I-VIII, 309-371, IX-XIII, 1916.

along streams up nearly to the summits of the main ridges. A few cypresses (*Cupressus* sp.) occur on northerly slopes at from 8,500 to 9,000 feet.

The lodgepole pine (*Pinus contorta*) is the second most important forest tree on the San Pedro Martir Mountains. It is freely intermingled with the Jeffrey pine from 7,500 to 8,000 feet, and on northerly slopes above the latter altitude to the summit of the mountain it occurs in many small almost unbroken areas.

On the lower slopes the Parry pinyon (*Pinus quadrifolia*) constitutes the lower border of the forest. It occurs as a scattered growth near San Matias Spring and along the Rosarito divide to the tops of the cliffs at Matomi. It also forms a thin forest along the northwest base of the San Pedro Martir Mountains, as at Pinyon, and thence out over the foothills to the Alamo Plain and on both slopes of the Sierra Juarez below the yellow pines. The single-leaved pinyon (*Pinus monophylla*) is reported to occur below 4,500 feet on the desert eastern slope of this range. The common pinyon (*Pinus edulis*) is also reported to occur in these mountains and on the basal slopes of the San Pedro Martir range.

Extending over the foothills of the west slope of these mountains are many junipers (*Juniperus californica*). This species is particularly abundant on and about Alamo Plain and along the northwestern foothills of the San Pedro Martir Mountains. In addition to the coniferous trees, the quaking aspens (*Populus tremuloides*) and an oak (*Quercus chrysolepis*) occur in the higher parts of the San Pedro Martir, and the Palmer oak (*Quercus palmeri*) on the Juarez Mountains. Along the western slopes of these montains the woody vegetation is scattered and includes four species of *Ceanothus*, several species of *Arctostaphylos*, an elder (*Sambucus*), the chamiso (*Adenostoma fasciculatum*), the mountain mahogany (*Cercocarpus*), and the California holly (*Heteromeles*).

The western slope is much more abundantly clothed with vegetation than the eastern side, where the bare granite slopes facing the desert are excessively arid and have but scanty vegetation. In sheltered places, along the south walls of cliffs on the east side at the head of Canyon Diablo, we saw scrubby pinyon pines growing at an altitude of 9,000 feet, thus showing the effect of the desert heat in carrying Upper Sonoran Zone plants far up through the Transition Zone.

From the basal foothills on the western slope of these mountains a belt of partly brush-grown valleys and ridges extends westward to the coastal range. There and on sheltered slopes occur scattered thickets made up of various species of shrubs and medium-sized live oaks, the latter mainly in canyons draining to the west. Some cottonwoods and sycamores grow in these canyons from near Ensenada southward to opposite San Quintin. In addition to the cottonwoods and sycamores some of the characteristic trees and shrubs occurring in the outlying western foothills of the mountains and along the Coast Range near Ensenada are the California live oak (*Quercus agrifolia*) and scrub oak (*Q. dumosa*), several species of *Eriogonum*, *Ephedra californica*, a buckeye (*Aesculus*), an ash (*Fraxinus attenuata*), and two species of black sage (*Artemisia*). The east slopes of the Juarez and San Pedro Martir Mountains, as already noted, are extremely rocky, steep, and barren, and the forest commonly ends at a higher altitude than on the west side. Fan palms are the only tree growth in the canyons leading down through the foothills on the eastern side and even these are lacking in many canyons.

From the southern end of the San Pedro Martir Mountains no forests of timber exist until the Sierra de la Laguna, at the northern end of the Sierra Victoria, in the cape district, is reached, a distance of more than 500 miles. There the summit of the Sierra Victoria for about 15 miles along its northern end and mainly on the east slope is capped by a scrubby forest of live oaks, picturesque madroños, and various scattered shrubs. Over a few square miles of the higher parts of the extreme northern end of the range, known as the Sierra de la Laguna, an abundant growth of scrubby pinyon pines is mixed with the oaks. The forest of pinyons and oaks on these mountains has its lower limit close to the summit on the abrupt west slope and is above 4,000 feet on the eastern side. Bare grassy slopes are numerous in this forested

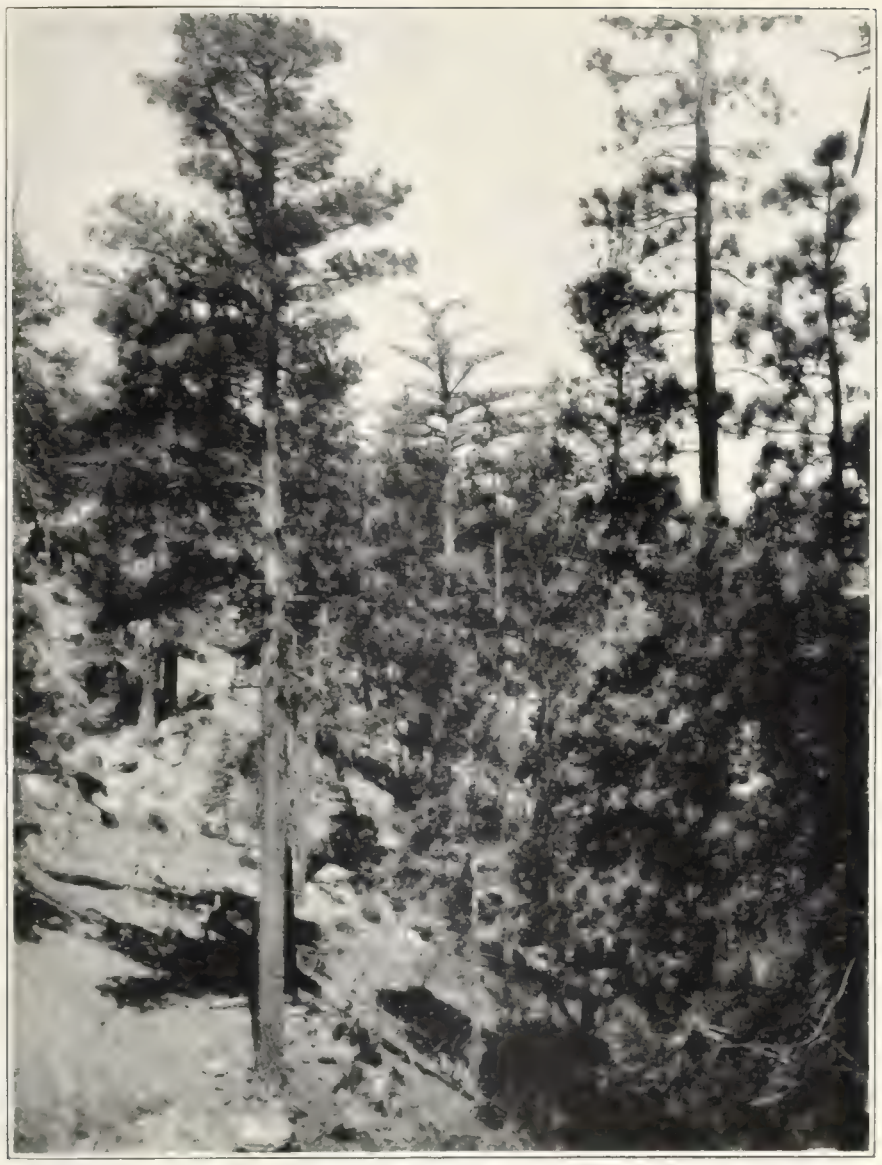

FIG. 1.—Forest of yellow pine (*Pinus ponderosa jeffreyi* and sugar pine (*Pinus lambertiana*) near Vallecitos, San Pedro Martir Mountains. The sugar pine in the middle background shows the characteristic branching of this species.

Desert vegetation at Arroyo Cataviña on granite tableland south of Llano de los Buenos Aires. The picturesque plant life of this locality gives the landscape an appearance suggesting that of some remote geological time.

area, mainly on the south exposures. Below the oak forest are open hillsides with a few oaks of another species (*Quercus brandegei*) which follow the canyons and range out to the bottom of the San Jose Valley at Miraflores. In the deep foothill canyons of the Sierra Victoria are many extremely tall, slender-trunked fan palms and a tall, handsome cottonwood of a local species (*Populus monticola*), which has white bark almost like that of an aspen. (See Pl. 19, Fig. 2.) The lower half of the mountain slopes are occupied by a scattered mixture of cactuses, agaves, and other species belonging to the desert lowland flora, mixed with numerous Arid Tropical species having their nearest relatives on the shores of Sinaloa across the gulf. The pinyon pine on the Victoria Mountains has been identified as typical *Pinus cembroides*, the form common on the mountains of the Mexican mainland. All three of the oaks we found on these mountains and the adjacent lowland to the east proved to be undescribed species, apparently related to those of the Mexican mainland and not to those of California. Growing on the higher parts of the Sierra de la Laguna, Belding's nolina was one of the most characteristic species, and a willow, a hackberry, a *Thalictrum*, the California holly, a Garrya, and a *Ribes* were other characteristic shrubby plants there. None of the forest growth on the Victoria Mountains is of sufficient size to be of more than local use for mining timbers or some similar purpose and is extremely inaccessible for any practical use.

The tops of the higher mountains seen by us during our journey from the southern end of the San Pedro Martir Range to the Sierra Victoria, with a single exception, were devoid of any sign of oak or pine trees. The one exception was on a high mountain lying southeast from the head of Calamahue Canyon, where we saw a few scattered scrubby trees near the summit on the north slope, which might have been either oaks or pinyon pine, but were probably the former. They were too far away to be positively determined.

The early Spanish missionaries are reported to have cut trees for timbers used in building the missions at Calamahue and San Borja on the tops of these high mountains near the head of Calamahue Canyon. In the fall of 1719 Padre Ugarte found some thick-trunked trees, which were called "Guarivos," in the canyon of the Santa Lucia Range about 30 leagues northwest from Mulege. The logs were hauled from there to the coast, where a small vessel was built which was used to explore the coast of the gulf.[1] These trees were probably the tropical palo blanco (*Lysiloma candida*) which is plentiful in some of the canyons on the west slope of the great lava plateau.

Other trees derived from the mainland mountains of southern California grow on Cedros and Guadalupe Islands off the west coast of the peninsula. The upper northwestern slopes and crests of the mountains on the northwestern part of Cedros Island are exposed to the cool, fog-laden northwest winds of the Pacific and are clothed with California junipers and scrubby pine trees (*Pinus muricata*), the latter sometimes reaching a height of over 60 feet. This forest is of no considerable extent and not of commercial importance. On Guadalupe Island the entire northwestern summit was formerly covered with a forest of Monterey pines (*Pinus radiata*), which is now reduced to a rapidly decaying strip along the northwestern crest and down the adjacent western slope. On the highest part of the Island, north of Mount Augusta, a large cypress forest (*Cupressus guadalupensis*) exists, which W. W. Brown estimated in 1906 to cover about 38 square miles. Well down the northwestern slope is a large fan-palm grove (*Erythea edulis*) containing some fine oak trees (*Quercus tomentella*).

Early botanical exploration (1874 and later) proved the existence on the island of 145 species of plants, including numerous shrubs, but since then goats have become so abundant that they have greatly reduced the vegetation. Some species have already been exterminated and others are going.

Plants Derived Mainly from the Deserts of Northwestern Sonora and the Southwestern United States.

As detailed in the preceding account of its climate, Lower California as a whole has extremely scanty rainfall, and periods of several successive years occur during which no precipitation takes place over great areas. Under the severe desert conditions thus produced the

[1] Venegas, Noticia de la Calif., II, p. 317, 1757.

peninsula has developed the richest and most varied desert flora known in America and probably in the world. This flora covers at least two-thirds of the total land area of the peninsula, including most of the lowlands and nearly all of the lower mountains and mountain ranges. The deserts extend from the northern boundary at the delta of the Colorado to the southern extreme at Cape San Lucas and from coast to coast. They also extend from sea level up to from 3,000 to 5,000 feet, or even higher in some places.

In areas where for various reasons the soil conditions are unfavorable, the desert is a bare sun-baked waste or has a scanty and stunted vegetation. These extreme conditions are especially prevalent on the slopes of the desert mountains. In other places where a deep sandy loam affords a favorable medium for retaining water after the infrequent rains, vegetation is extraordinarily abundant and veritable forests of desert plants from 10 to 50 feet high are found, often becoming almost impenetrable thorny jungles. (See Pl. 28, Fig. 1.) This vigorous desert growth occurs in places along the eastern base of the San Pedro Martir Mountains, but is especially notable along the great interior plateau extending from southeast of San Fernando to the northern end of the Victoria Mountains south of La Paz. The plants of this great region exhibit an amazing and fantastic variety of forms grouped in endless combinations, thus giving the landscapes an extraordinary aspect. The cactuses are the most generally distributed and varied family of desert plants in this region, presenting a marvelous variety, from species creeping over the ground like huge spiny caterpillars several yards long (*Lemaireocereus eruca*), to giant arborescent species with trunks two or three feet in diameter and 50 or 60 feet high (*Pachycereus pringlei*). (See Pls. 8 and 14.) One slender species lies prone on the ground, another climbs and spreads like a vine among low tree tops, while still others have single corpulent barrel-like trunks 6 or 8 feet high. All are armored with defensive spines, some short and closely set, others like slender needles several inches long, and still others strong and rigid with recurving hooks at the tip and so closely set as to form a powerful defensive armor covering the entire plant.

The cactuses of the peninsula belong to 11 genera, including *Bergerocactus*, *Echinocactus*, *Echinocereus*, *Lemaireocereus*, *Lophocereus*, *Mamillaria*, *Myrtillocactus*, *Opuntia*, *Pachycereus*, *Pereskiopsis*, and *Wilcoxia*. Other striking and characteristic associated plants are numerous species of yuccas, agaves, nolinas, ocotillos (*Fouquieria*), the palo verdes (*Cercidium* and *Parkinsonia*), ironwood (*Olneya*), creosote bush (*Covillea*), mesquite, acacias, and several species of fan palms of the genera *Washingtonia* and *Erythea*. Both genera of fan palms occur from near the northern border to the southern end of the peninsula. According to Orcutt they occur in the basal canyons on the east slope of the Sierra Juarez and along the courses of many canyons and gulches where water is near the surface, in the desert mountains and plateaus of the eastern and middle parts of the peninsula. South of Todos Santos they appear also on the Pacific coast. In addition to the canyons along the east base of the Sierra Juarez fan palms are abundant in Matomi Canyon, in the canyon where the ruins of the Santa Maria Mission are located, along the arroyos of Jaraguay and Cataviña, and in numerous other places. In the extreme south they are numerous on the coastal plain at Pescadero and on the west side of the San Jose Valley as well as in the basal canyons of the Sierra de la Victoria.

In addition are several desert species which seem like plant monstrosities. This is peculiarly the case with the elephant wood, which has a short thick trunk and contorted branches covered with a smooth, skinlike bark which lies in thickened folds and creases, giving the tree a dropsical appearance. (See Pl. 28, Fig. 2.) Contrasting with this is the cirio (*Idria columnaris*), which is a tapering, polelike tree growing from 20 to over 50 feet high, with short, slender, and thorny branchlets forming a bristling armament along its trunk. This strange tree has tufts of pale yellow flowers rising on long slender stems from the tip of the trunk, which is covered with a smooth greenish-yellow bark. The tapering yellowish trunk and rootletlike branches give the cirio a close resemblance to a gigantic slender parsnip bottom side up. (See Pl. 29, Fig. 1.)

The southern end of the Colorado Desert occupies northeastern Lower California and includes the delta of the Colorado River. Many of the islands in the delta and some of the adjoining delta plain are thickly overgrown by Macdougal's cottonwood (*Populus macdougalii*). Great

numbers of these are washed away during spring floods when the banks where they grow are cut away by the river, as illustrated in a photograph taken in April, 1905. (See Pl. 23, Fig. 1.) These trees occur at Ojo de Liebre, in the Vizcaino Desert, and at occasional ranches to the southern end of the peninsula. The delta islands and adjoining delta plain are also overgrown with willows and the arrowwood (*Pluchea sericea*). Away from the river the lower and more barren parts of the desert have a scanty growth, including the creosote bush, an ephedra (*E. trifurca*), the screwpod and common mesquite (*Prosopis pubescens* and *P. juliflora*), a dalea (*Parosela spinosa*), a copal (*Elaphrium macdougalii*), the ironwood (*Olneya tesota*), several species of cactus, and others.

The infrequent rains of this part of the desert often come in the form of tremendous showers which send many temporary torrents across the sloping plains, thus making a series of washes leading to a main drainage channel which at such times may become an impassable torrent. At other times these drainage ways are dry washes, along which, owing to the greater amount of moisture they receive, grow long lines of creosote bushes, mesquites, and other shrubs which mark their courses.

In addition to the common cottonwood, the palo verdes (*Cercidum torreyanum* and *Parkinsonia aculeata*), the common mesquite (*P. juliflora*), the ironwood, the creosote bush, the copal (*Elaphrium microphyllum*), a *Simmondsia*, several species of *Lycium*, *Baccharis*, and the brittle bush (*Encelia farinosa*), besides others, occur in the desert throughout the length of the peninsula. No giant cactuses occur about the delta of the Colorado but they grow abundantly along the east base of the San Pedro Martir Mountains, and one or the other of the three species of giant cactuses known from the peninsula occurs continuously thence to Cape San Lucas.

Large numbers of the woody plants of the desert grow to the size of low trees from 12 to 30 feet in height and in connection with the cactuses, yuccas, agaves, and cirios in many places form extensive forests. These forests are largest along the middle of the elevated interior plateau on the western slope from San Fernando to opposite Magdalena Bay, and again about the base of the Victoria Mountains in the cape district. In the middle of the peninsula from near San Fernando to beyond Calmalli the polelike cirio gives a remarkably distinctive character to the forests, which consist, in addition to the species named above, of numerous cactuses, agaves, acacias, mesquites, huisaches (*Vachellia farnesiana*), cassias, euphorbias, jatrophas, fouquierias, the elephant wood, grease wood (*Atriplex*), and numerous others. Over considerable areas near Santo Domingo forests occur composed almost entirely of *Yucca valida*, with a mixture of only a few other prominent plants. (See Pl. 29, Fig. 2.) Other areas in this section contain forests made up almost wholly of species of agave.

In canyons, from near the northern border on the east base of the Juarez Mountains south to the cape district, fan palms of the genera *Washingtonia* and *Erythea* occur and add a most picturesque element to the scenery. (See Pl. 17, Fig. 2, and Pl. 27.) The large number of date palms in the oases from the middle of the peninsula south and the coconut palms in the cape district are beautiful introduced additions to the flora. (See Pl. 13, Fig. 2.)

The eastern and western sides of the peninsula vary in the amount of their vegetation. The east coast is much hotter and drier than the west, which is shown strikingly throughout the peninsula north of La Paz by the abrupt and marked change in the character of the vegetation from the abundant growth on the western slope to the generally sparse and often extremely desert character of that on the east side of the main mountain ranges forming the backbone of the peninsula. This is due mainly to the effect of the barrier formed by the mountain ranges which extend the entire length of Lower California and thus cut off the cool, moist, and often foggy northwestern trade winds. This aridity of the east coast is in part due also to the proximity of the east slope of the mountains to the Gulf of California, which is so inclosed by land, especially about its northern two-thirds, that in summer the surface water becomes heated to a temperature far above that of the Pacific on the opposite shore and thus helps hold the general temperature of the air at a higher point.

In the lowland areas, as well as elsewhere on the west side of the peninsula, vegetation is decidedly benefited by the condensation upon it of moisture contained in the sea fogs which

prevail and are drifted inland at certain seasons. The observations of W. W. Brown, in early May, 1906, on Guadalupe Island well illustrates this. The pines on Guadalupe grow along a precipice nearly 3,000 feet high on its western side, and when the prevailing northwest wind blows in the fog from the surrounding ocean he noticed that the ground at some distance from the pines looked scarcely dampened, while small streams of water which had condensed in the tree tops were running down the tree trunks and away from their bases.

In addition the cool breezes of the Pacific have a distinct effect on the vegetation of the small coastal islands and on a narrow belt from one to several miles in breadth along the western shore of the peninsula. This becomes gradually less toward the cape district, but is strongly marked throughout most of the distance. The sea breezes appear to prevent the growth of trees and shrubs, so that the hill slopes and plains close to the sea and the small islands are clothed with grasses and other small vegetation, including a few stunted woody plants, some of which are peculiar to these locations. The slopes of some of the islands along the northwest coast are covered with great beds of the curious ice plant (*Mesembryanthemum crystallinum*), and San Martin Island is characterized by the abundant beautiful velvety white cotyledon *Dudleya anthonyi*.

In sheltered gulches and canyons of the coast hills and mountains, where they escape the direct effect of the sea winds, and on sheltered sides of the islands small shrubs grow abundantly. The cool, moist sea winds along the northwest coast cause an abundant growth of small lichens on the stones, and on the trunks and branches of shrubs and other objects along the open belt immediately bordering the shore of the mainland and of the outlying islands. Farther inland, where the heavy growth of desert shrubs and other vegetation forms a jungle in many places, these cool winds and fogs favor the growth of large numbers of tillandsias and various species of epiphytic plants. Most important of these is the orchilla (*Roccella*), a species of lichen which is valuable for dyeing purposes. This plant hangs from the branches of cactuses, low trees, and shrubs, like Spanish moss, which it greatly resembles in general appearance and color. It grows mainly along the coastal plain from Ballenas Bay to Magdalena Bay, and was formerly the basis of a profitable industry. The accompanying photograph illustrates this semiparasitic growth on the desert vegetation along the seacoast near San Andres. (See Pl. 30, Fig. 1.)

The vegetation on the islands on both coasts is made up mainly of the same species occurring on the nearest adjacent part of the mainland of the peninsula with the exception of Guadalupe. On this island the vegetation appears most closely related to that of the coast of middle California, as illustrated by the appearance of a juniper, a cypress, and the Monterey pine.

Plants Derived from the Lowlands and Mountains of Sinaloa and Southern Sonora on the Mainland of Mexico.

As shown by the lists in the account of the life zones of the peninsula, large numbers of plants in the southern end of Lower California belong to the arid tropical genera common in Sinaloa, on the Mexican mainland. Many of these are among the large and conspicuous species characterizing the lowlands, hills, and mountain slopes of the cape district up to over 4,000 feet altitude. Some of the species appear to be common to both sides of the gulf, but most of them are undoubtedly peculiar to the peninsula. Among the numerous Arid Tropical genera of the cape district, which also characterize the flora of the mainland across the Gulf of California, may be mentioned *Ficus*, *Lysiloma*, *Mimosa*, *Cassia*, *Erythrina*, *Albizzia*, *Jatropha*, *Hæmatoxylon*, *Xanthoxylon*, *Lantana*, *Elaphrium*, *Manihot*, *Lippia*, *Bourreria*, and *Chiococca*.

Many of the tropical species of the southern end of Lower California are included in the account of the Arid Tropical life zone of the peninsula, and to save repetition reference is made to that part of this work (pp. 122–123). In addition to the tropical species of the southern end of the peninsula, the trees of the higher mountains in that region appear also to have been derived from the Mexican mainland rather than from the north. This is indicated by the fact that the pinyon pine in the small forest on the Sierra de la Laguna has been identified by Mr. Shaw as typical *Pinus cembroides*. The three species of *Quercus* appear to be related to

Fig. 1.—Jungle of cactuses, yuccas, and other thorny plants in northern part of Vizcaino Desert, west of Calmalli. Growth of this character in many places is impenetrable for man or horse without cutting the way.

FIG. 1.—Forest of cirio (*Idria columnaris*) near San Fernando. This remarkable tree is peculiar to Lower California and is the prevailing species for hundreds of miles on the granite tableland.

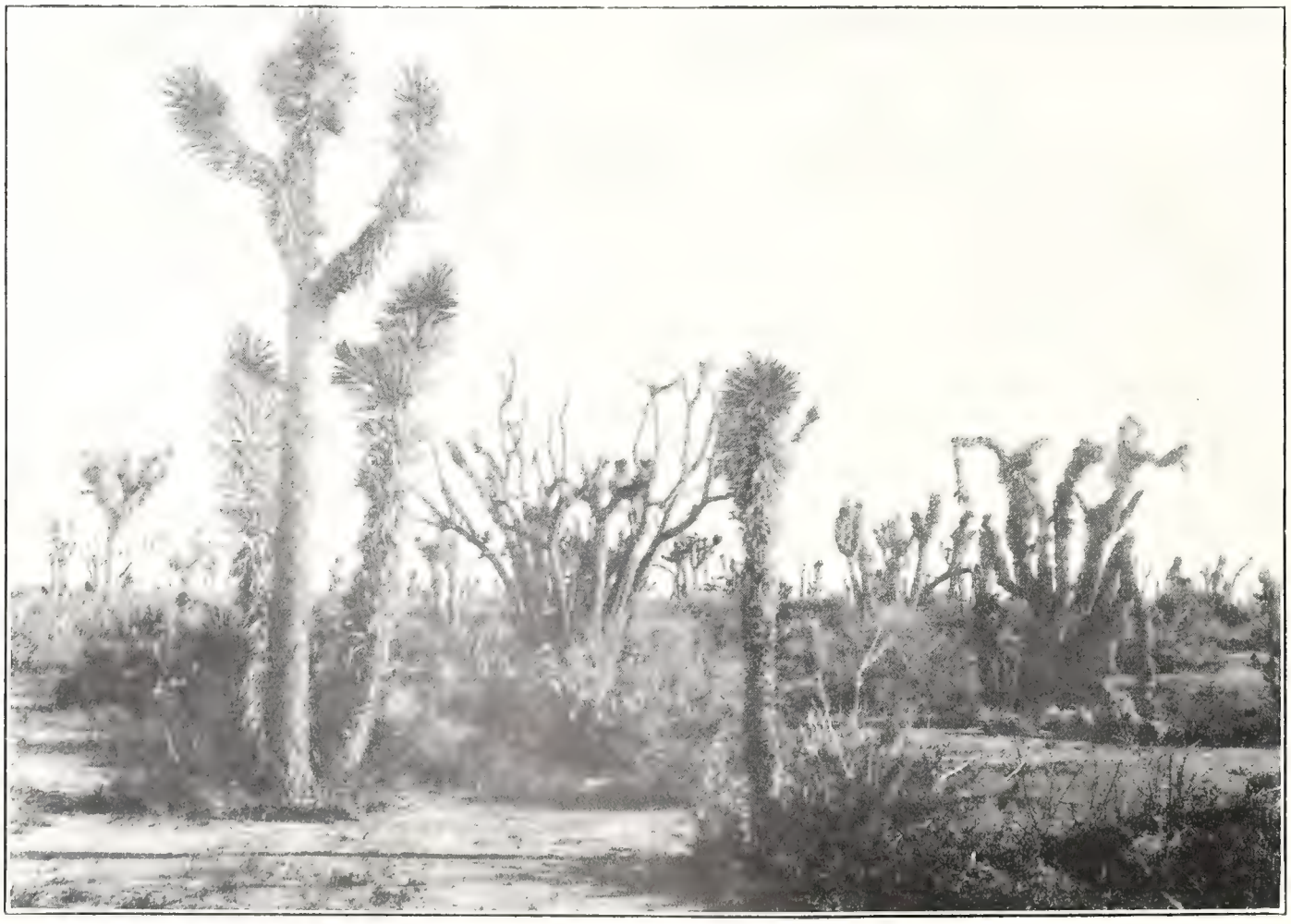

FIG. 2.—Forest of *Yucca valida* near Santo Domingo Landing. This extraordinary growth extends irregularly for miles.

FIG. 1.—Orchilla (*Roccella*) growing on fouquieria bush near San Andres. This dye plant, of the color and general appearance of the Spanish moss growing on trees of our Gulf States, was formerly exported by shiploads to Europe from Magdalena Bay. The production of analine dyes killed this industry.

FIG. 2.—Epiphytic plants growing on desert shrubs in foggy coast belt near San Andres.

oaks on the mainland across the gulf rather than those of the north, and a large madronyo (*Arbutus peninsularis*) is not represented on the San Pedro Martir Mountains in the north but has a close relative on the mainland mountains across the gulf. About the heads of sheltered bays and lagoons from the boat landing at San Jorge above Magdalena Bay southward around Cape San Lucas and up the east coast nearly to Santa Rosalia the mangrove (*Rhizophora mangle*) is common. The most extensive growth of this well-known tropical plant occurs in the lagoons extending northward from the head of Magdalena Bay. Elsewhere it grows in more or less limited areas on Margarita Island, at Cape San Lucas, at the head of La Paz Bay, and in small areas northward along the coast, as well as on several of the islands in the southern part of the gulf.

Two species of wild cotton have been found native in the southern end of the peninsula, one in the cape district north of La Paz (*Gossypium davidsoni*) and the other on Margarita Island (*G. harknessi*). The ordinary domesticated cotton (*G. herbaceum*) was formerly cultivated from Cape San Lucas north to the mission of San Fernando.

Like the deciduous trees of the low Arid Tropical forests on the west coast of Mexico many of the low trees of the cape district, especially among the leguminous forms, have a tendency to flattened, broadly spreading tops. In some of the valleys and low canyons of the cape district the *Washingtonia* fan palm is common. The other genus of fan palm of this district (*Erythea*) is represented in canyons of the Victoria Mountains by groups of excessively tall, slender-trunked individuals growing often 100 or more feet high and only 6 to 12 inches in diameter. (See Pl. 19, Fig. 2.) The wild fig (*Ficus palmeri*) occurs as scattered individuals in situations where water is close to the surface, from near the middle of the peninsula south to the cape district, where it is more numerous than elsewhere. It ranges up to nearly 4,000 feet in the foothills.

The Arid Tropical element probably does not include more than 50 per cent of the entire vegetation of the lowlands of the cape district, since it is intermingled with nearly an equal number of desert species coming down from the north. These representatives of the northern deserts include two species of the giant cactus and many other members of the same family, with the creosote bush, fouquierias, mesquites, acacias, palo verdes, ironwood, the brittle bush, and numerous others. The southern end of the great Magdalena Plain, including its extension to the head of La Paz Bay and the mountain group called the Cacachilas, are rather poorly clothed with vegetation, the heavy growth thus being limited to the middle and northern part of this plain.

The northern foothill slopes of the Sierra Victoria, along the wagon road from La Paz to Todos Santos, are covered with a heavy forest growth of giant and other cactuses, mesquites, acacias, and many species of arid tropical trees and bushes from 10 to 30 feet high, forming in many places a dense thorny jungle. The same vigorous growth exists along the sloping sandy valley leading down from the southern end of the Victoria Mountains to the bay at Cape San Lucas. In the San Jose Valley, especially along the middle of its course and on the foothill slopes along its borders between Santa Anita and Miraflores, this growth is especially abundant. On the basal foothill slopes back of Miraflores the arid tropical element is unusually well marked by the number of tropical bushes and small trees.

On the part of the Magdalena Plain lying north of Matancita occur some areas of extremely large and abundant desert growth, including vigorous mesquite trees, which indicates the presence of water at a comparatively small depth below the surface of the rich soil. We also noted a heavy growth of large mesquite trees in El Potrero Valley a few miles above Mulege.

The flowering season of plants in Lower California is largely governed by the rainfall, and many of the small herbaceous species spring up quickly and flower after a heavy rainfall at any time during the warm season. Many of the desert plants, however, have developed the power of storing sufficient moisture and food during the occasional rains to enable them to flower and fruit successfully, even during seasons when no rain falls. Cactuses, agaves, yuccas, nolinas, mesquites, palo verdes, and numerous others need rain only at wide intervals to enable them to flower and fruit more or less regularly in spring or summer. During their period of blossoming

the mesquites and palo verdes are masses of small but attractive flowers which collect swarms of insects. The handsome flowers of the cactus vary from white to red and yellow, and the wonderful masses of white blossoms of the yuccas are among the beautiful sights of the desert. The flowering season in the high mountains of the north is delayed owing to the much colder winters, but it opens early in the Victoria Mountains of the cape district, where on the 1st of February Belding noted a blackberry, a black currant (*Ribes brandegei*), the madroño (*Arbutus peninsularis*), a monkey flower (*Mimulus*), the painted cup (*Castilleja*), a lupine (*Lupinus*), and other plants in blossom. Eisen writes that the cape district is frequently ablaze with the yellow flowers of the palo de arco (*Tecoma stans*) and a large morning glory (*Ipomea aurea*).

As noted elsewhere, a number of species of trees of economic value to the natives have been brought to the cape district from the Mexican mainland among which the coconut and date palm, the gourd tree (*Crescentia cujete*), the tamarind (*Tamarindus indica*), and *Pithecolobium dulce* are among the most notable. The latter and the tamarind have in a number of places escaped from cultivation and now form part of the forest growth.

ANIMAL LIFE.

Although Lower California is mainly a desert its long coast line, varied surface, and great extent in latitude combine to give it a varied and interesting fauna. The peninsula extends into the border of the Tropics, but its vertebrate land fauna is almost wholly derived from the adjacent arid region to the north and contains representatives of nearly all the genera and species of the southwestern desert region of the United States. The considerable variety of the vertebrate fauna of the peninsula appears from the fact that it is known to contain approximately the following: Five genera and 5 species of amphibians, 33 genera and 75 species and subspecies of reptiles, 244 genera and 428 species and subspecies of birds, and 51 genera and 166 species and subspecies of mammals. The most notable characteristics of the fauna of Lower California are the preponderance of desert land species of reptiles, birds, and mammals, and the number and variety of marine mammals.

The pronghorn antelope, mule deer, mountain sheep, and mountain lion are the big game animals. Of these the antelope, which once occupied suitable areas practically throughout the peninsula, is gone from most of its former range and is on the way to early extinction. The mountain sheep is still widely distributed on the main mountains of the eastern half of the peninsula, but in addition to being hunted for sport is being slaughtered without regard to age or sex to supply mining camps and small towns with meat, and must soon follow the antelope unless effectively protected. The deer are more generally distributed and will hold their own much longer than the antelope and sheep, but they also have become much scarcer in many places and are practically gone in others.

The only record I have found of bears in Lower California is the reference in Pattie's narrative to the presence of grizzlies near Santa Catarina Mission in the Sierra Juarez.[1] Mountain lions, wild cats, coyotes, badgers, and gray foxes occur throughout the peninsula, while the small desert fox ranges south to the Llano de Yrais, opposite Magdalena Bay. There is no trustworthy record of wolves anywhere in Lower California. The jaguar is said to have occurred at a very early date in the delta of the Colorado. Beavers were formerly extremely numerous in the delta, but owing to trapping are now present in much smaller numbers. The plains and valleys in many places throughout the peninsula swarm with desert rodents, including jack rabbits, cottontails, kangaroo rats (*Dipodomys* and *Perodipus*), pocket mice (*Perognathus*) of several species, various species of white-footed mice (*Peromyscus*), and wood rats (*Neotoma*). The antelope squirrel (*Ammospermophilus*) is also common south of Cape San Lucas.

The falling fruit of the date palm groves in the middle of the peninsula, as at San Ignacio, Mulege, and La Purisima, attract many gray foxes, bassarisks, and little striped skunks, which make their homes in the neighboring lava cliffs.

[1] Thwaites, Early Western Travels, XVIII, p. 221, 1905.

When Lower California was discovered its shores swarmed with whales, elephant seals, fur seals, and sea otters, and small game abounded.[1] Several species of whales had their breeding grounds in sheltered bays on both coasts and these mammals were so numerous that the early Spanish navigators named for them Ballenas Channel in the Gulf of California and Ballenas Bay on the Pacific coast. During the first two-thirds of the last century the abundance of whales about these shores attracted many whaling ships, mainly under the American flag, until the hosts of California gray and sperm whales were either killed or driven away and whaling became unprofitable and was entirely abandoned. During the last few years whaling on the Pacific coast has revived with the use of steam-powered ships and may have an even more disastrous effect on the whales than the former industry.

Capt. Scammon states that the great abundance of whales in the bays of Lower California became generally known to whalers during the winters of 1846 and 1848, and in the last-named winter 52 whaling ships anchored in Magdalena Bay.[2] Since the whaling activity in the period which immediately followed the whales have never recovered anything approaching their former abundance. During the same time the Guadalupe fur seal, northern elephant seal, and sea otter were pursued by many hunting ships and slaughtered so ruthlessly that this fur seal is now supposed to be extinct and the elephant seal and sea otter are on the verge of extinction, if not already gone.

Scammon Lagoon, at the head of Vizcaino Bay, was first explored by Capt. Scammon in 1858. He found its waters alive with whales, porpoises, and fish. Turtles and seals basked on the shores of low islands studding the lagoon, and small game was so abundant that acres of sand bars bared by the tide were closely packed with wild geese, ducks, snipe, and other waterfowl.[3] Capt. Scammon in his "Marine Mammals" has given us the only connected account of the wonderful abundance of animal life at one time existing on the northwest coast of Lower California.

In one of the early accounts Padre Taraval is quoted concerning the abundance of sea otters on Cedros Island at the time of his visit in 1737, and describes the ease with which they were killed by the Indians.[4] Under Spanish rule sea otter hunting and trading in their domain by foreign ships was prohibited, but many thousands of skins were traded for by smuggling and hunting vessels along the Pacific coast early in the last century. One ship alone secured 1,700 sea otter skins from the natives during a single visit to Ensenada in 1809.[5]

The variations in the annual rainfall on the peninsula have a direct influence on its animal life, which is strongly shown in the case of some of the mammals. During series of consecutive heavy rains the desert vegetation flourishes exceedingly, great quantities of seeds are ripened, tender vegetation abounds, and desert mammals, especially the small kinds, such as pocket mice and kangaroo rats, increase enormously until favorable areas swarm with them. When the long rainless periods follow, the herbage ceases to grow, no seeds are ripened, and there is a resulting scarcity of food, and an enormous mortality among the small inhabitants of the desert. The same cause also has its effect on the abundance of rabbits, deer, and antelope. Other less obvious causes also bring about great local temporary changes in the numbers of small mammals. This was shown strikingly during the early part of our journey, when we visited localities where Heller found certain pocket mice abundant in the summer of 1902, and we found them extremely rare or entirely absent during the summer of 1905, although the same or closely allied species were plentiful in other areas of the same region.

Lower California exhibits some striking contrasts under which its animal life exists. In the cape district deer and many birds winter on the Sierra de la Laguna, where snow never falls, while Anthony tells me that on the San Pedro Martir Mountains, in the north, snow at times falls to a depth of 6 feet and the deer and quail are forced down to the basal slopes on the west side.

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[1] Several of the early visitors to the shores of the peninsula record the abundance of small game, as in the case of the British exploring ship, *Herald*, which called at San Quintin Bay, Oct. 15, 1846, and Seemann, the naturalist of the expedition, mentions the abundance of "rabbits, hares, quail, curlew, sanderling, mackerel, smelt, and cray fish."

[2] Overland Monthly, IV, pp. 230–238, March, 1870.

[3] Scammon, Suppl. App., p. 123, in Browne's Resources of the Pacific Slope, 1887.

[4] Venegas, Noticia de la Calif., vol. 2, p. 438, 1757.

[5] Suppl. App., p. 42, in Browne's Resources of the Pacific Slope, 1887.

On the islands about the coasts of the peninsula numerous species of sea birds have their nesting colonies. On the Pacific coast islands such species as murrelets, western gulls, petrels, shear waters, cormorants, California brown pelicans, and man-of-war birds breed in large numbers. On the islands in the Gulf of California are breeding colonies of murrelets, Heermann's gulls, elegant terns, red-billed tropic birds, Brewster's and blue-footed boobys, cormorants, California brown pelicans, and man-of-war birds.

The resident birds of the plains and foothills of the peninsula are mainly species or subspecies closely related to well-known forms of the cactus deserts of the southwestern United States and northwestern Sonora, Among the most notable of these are the elf owl (*Micropallas whitneyi*), the road runner (*Geococcyx*), several subspecies of the ladder-backed woodpecker (*Dryobates scalaris*) and of the Gila woodpecker (*Centurus uropygialis*), the gilded flicker (*Colaptes chrysoides*), and two forms of the ash-throated flycatcher (*Myiarchus cinerascens*); also the desert sparrows (*Amphispiza*), the cardinals (*Richmondena* and *Pyrrhuloxia*), the phainopepla, the mocking bird, several species of desert thrashers (*Toxostoma*), the cactus wren (*Heleodytes*), the rock wren (*Salpinctes*), and the verdin (*Auriparus*). A considerable infusion of the Californian fauna coming in from the northwest, includes the valley quail and subspecies of the California jay which are common south to Cape San Lucas. In the higher mountains there is a fair representation of genera from the mountains of southern California. In summer enormous numbers of shearwaters and petrels visit the northwest coast, and in winter vast numbers of waterfowl resort to the delta of the Colorado, and to San Quintin and other bays on the west coast.

The general decrease of migratory waterfowl in North America is evidenced by their decrease along this coast in winter, while some of the resident marine waterfowl breeding on the coastal islands, as gulls, pelicans, and cormorants, have been reduced by unrestricted persecution in the breeding season by guano hunters.

During our journey through the middle of Lower California in the autumn of 1905 the scarcity of migrant birds was notable. At the southern end of the peninsula, the warm pleasant winter climate and plentiful vegetation appeared well adapted to render it an attractive winter home for species breeding in the north. We found such birds, however, in surprisingly small numbers compared with those living at this season along the neighboring mainland coast of Mexico. The small number of such birds as *Dendroica auduboni* and *Vermivora celata lutescens* was difficult to understand. It was equally unexpected to find the lark bunting (*Calamospiza melanocorys*) plentiful in flocks on the cactus-grown Magdalena Plain and about the base of the Victoria Mountains. Most of the resident land birds of the peninsula occupy the same area throughout the year, but the apparent absence of *Crotophaga sulcirostris*, *Myiochanes richardsonii peninsulae*, and some other summer residents of the cape district during the winter of 1906 appeared to indicate a migration of these species across the gulf to the Mexican mainland. From the foregoing it appears that Lower California is well outside (west of) the regular bird migration routes and has comparatively few stragglers from the great army of migrants which twice a year sweeps over the Mexican mainland.

The most remarkable bird records ever made in Lower California are those of Lyman Belding, who collected a specimen of *Vetola lapponica baueri* at La Paz, the winter of 1881–82; one of *Motacilla ocularis* at La Paz, on January 9, 1882; and one of *Anthus cervinus* at San Jose del Cabo, January 26, 1883—all birds of eastern Siberia and occasionally found in Alaska in summer and in southern and eastern Asia in winter. The occurrence of these birds so far from their natural haunts must have been due to some remarkable storm.

The waters of the gulf are warmer than those of the Pacific coast of Lower California. This is shown by the molluscan fauna which, as stated by Dr. Cooper, is much more tropical in character in the gulf than on the Pacific coast. In the northern part of the gulf, however, "the species are largely of the temperate fauna, many of them identical with those for the same latitude on the west coast of the peninsula. This seems to indicate that the dividing ridge [of the peninsula], now more than 1,000 feet in altitude in the north, was crossed by one or more channels within geologically recent times.[1] " The low passes now known to exist across the peninsula at the head of Calamahue Canyon, and again northeast of Calmalli, probably not exceeding 1,200 or

[1] Proc. Calif. Acad. Sci., 2d ser., V, p. 37, 1895.

1,800 feet in height, may have been the submerged routes through which northern sea shells reached the head of the gulf.

The southern part of the gulf coast once abounded in the pearl oyster, which supported a profitable industry, but the beds have been so worked out that the industry has greatly declined. The artificial propagation of the pearl oyster was begun on some of the gulf islands near La Paz, in 1903 or 1904, and at the time of our visit in 1906 was reported to be succeeding. Some years later these plantings are reported to have been successful and may indicate a method of reviving the pearl industry. Sea turtles breed in great numbers in the lagoons and bays along the shores and some were shipped by the monthly steamers from Magdalena Bay to San Francisco in 1905. Unrestricted exploitation of this resource will no doubt result in its destruction, as in the case of the marine mammals. Fish of many species are very numerous on both coasts of the Peninsula.

When the first summer rains come in parts of Lower California, both animal and plant life awakens suddenly into vigorous activity. The contrast is most impressive in the southern third of the peninsula—the cape district—where the climate is mainly arid tropical. There many of the birds are said to delay the beginning of their nesting period until the advent of the rains releases the swarms of insect life and renews vegetative activity. Dr. Eisen states that after the first rains in the cape district "nine-tenths of all chrysalises and larvae hatch at once and the whole country is teeming with animal life. The bushes and trees cover themselves with leaves and flowers, giving ample food for caterpillars and insects of all kinds. As this [the rainy season] begins in the sierra, the sierra is the proper place in which to begin explorations and collections. A week after the first rain the fauna is at its height. Myriads of butterflies are seen filling the air in the daytime, while during the evening hours microlepidoptera, or moths and beetles of all kinds swarm around the lights. Countless lizards dart among the rocks on the hillsides or in the branches of the trees. * * * I have seen so many butterflies filling the air in one of the high valleys of the Sierra El Taste that the air seemed thick with them, and this continued for several weeks. When at such a time a cloud over the sun caused a temporary shadow the innumerable host of butterflies suddenly vanished, having taken refuge on the underside of the leaves of trees, bushes and herbs." One day * * * "the whole valley between El Taste and Mt. Troyer was filled to a height of 3,000 feet, or from the bottom of the valley to the top of the peaks, and several miles in width, with butterflies in almost every color of the rainbow, but principally white and yellow. * * * One of the features of the fauna of the cape region is the immense quantity of land shells found in some places. In certain evidently favored localities the ground is literally covered with the dead and white shells of land mollusks. We ride along for hours through canyons where the ground is thus strewn. Then as we turn into another canyon, we find no shells at all, not even after close search under rocks and trunks of trees. * * * Another peculiarity as regards the land shells is that every sierra and every canyon almost possesses peculiar forms not found anywhere else.[1]" The early missionaries tell of enormous flights of grasshoppers which visited the cape region, devouring everything green and darkening the sky, but there is no modern record of such a visitation.

The following lists and remarks briefly characterize the vertebrate land fauna of Lower California and adjacent islands.

Amphibians.

As might be expected from the desert character of this region its amphibian fauna is extremely limited and none of the species are of tropical origin. Van Denburgh listed only five genera and five species;[2] to these must now be added two genera and three species, totaling as follows:

Batrachoseps attenuatus.
Plethodon croceater.
Ancides lugubris lugubris.
Scaphiopus couchii.
Bufo boreas halophilus.
Bufo punctatus.
Hyla regilla.
Rana draytonii.

None of these are peculiar to Lower California. The *Scaphiopus* ranges as far east as Texas, while the *Hyla* and *Batrachoseps* range some distance north along the Pacific coast. The known range of the *Plethodon* extends northward to the Sierra Nevadas of West Central California.

[1] Proc. Calif. Acad. Sci., 2d ser., V, pp. 760–762, 1895.

[2] Idem, pp. 356–361.

Reptiles.

Like the remainder of the vertebrate land fauna, most of the reptiles evidently invaded the peninsula from the arid land area of the adjoining part of the United States, with only a few representatives from the tropical mainland of Mexico. Aside from two species of sea turtles, the tortoise shell turtle (*Eretmochelys imbricata*) and the green turtle (*Chelonia agassizii*), Van Denburgh lists 31 genera and 62 species and subspecies of reptiles for the peninsula and adjacent islands,[1] to which must now be added 8 genera and 40 forms subsequently obtained within its limits, thus making a total of 39 genera and 102 species and subspecies.

REPTILES KNOWN FROM LOWER CALIFORNIA AND ADJACENT ISLANDS.

Phyllodactylus tuberculosus.
Phyllodactylus unctus.
Coleonyx variegatus.
Ctenosaura hemilopha.
Ctenosaura insulana.
Dipsosaurus dorsalis dorsalis.
Dipsosaurus dorsalis lucasensis.
Crotaphytus collaris baileyi.
Crotaphytus copeii.
Crotaphytus wislizenii.
Sauromalus ater.
Sauromalus hispidus.
Sauromalus interbrachialis.
Callisaurus carmenensis.
Callisaurus crinitus.
Callisaurus draconoides.
Callisaurus plasticus.
Callisaurus splendidus.
Callisaurus ventralis ventralis.
Uta concinna.
Uta graciosa.
Uta mannophorus.
Uta martinensis.
Uta mearnsi.
Uta microscutata.
Uta nigricauda.
Uta palmeri.
Uta parva.
Uta repens.
Uta squamata.
Uta stansburiana elegans.
Uta stansburiana hesperis.
Uta stellata.
Uta thalassina.
Sator angustus.
Sator grandævus.
Sceloporus graciosus vandenburgianus.
Sceloporus licki.
Sceloporus lineatulus.
Sceloporus occidentalis biseriatus.
Sceloporus orcutti.
Sceloporus zosteromus.
Phrynosoma blainvillii.
Phrynosoma cerroense.
Phrynosoma coronatum.
Phrynosoma platyrhinos.
Phrynosoma solare.
Gerrhonotus multi-carinatus.
Gerrhonotus scincicauda webbii.
Anniella pulchra.
Xantusia gilberti.
Verticaria cærulea.
Verticaria hyperythra beldingi.
Verticaria hyperythra hyperythra.
Verticaria sericea.
Cnemidophorus bartolomas.
Cnemidophorus celeripes.
Cnemidophorus labialis.
Cnemidophorus martyris.
Cnemidophorus maximus.
Cnemidophorus multiscutatus.
Cnemidophorus rubidus.
Cnemidophorus tessellatus stejnegeri.
Cnemidophorus vandenburghi.
Plestiodon skiltonianus lagunensis.
Bipes biporus.
Siagonodon humilis.
Lichanura roseofusca.
Lichanura trivirgata.
Coluber aurigulus.
Coluber constrictor flaviventris.
Coluber lateralis.
Salvadora hexalepis.
Phyllorhynchus decurtatus.
Elaphe rosaliae.
Pituophis catenifer annectens.
Pituophis catenifer deserticola.
Pituophis vertebralis.
Lampropeltis boylii boylii.
Lampropeltis boylii conjuncta.
Lampropeltis californiae.
Lampropeltis nitida.
Rhinocheilus lecontei.
Hysiglena ochrorhynchus.
Chilomeniscus fasciatus.
Chilomeniscus stramineus.
Natrix valida.
Thamnophis ordinoides hammondii.
Trimorphodon lyrophanes.
Tantilla planiceps.
Crotalus atrox.
Crotalus cerastes.
Crotalus enyo.
Crotalus exsul.
Crotalus lucasensis.
Crotalus mitchellii.
Crotalus oreganus.
Pseudemys ornata nebulosa.
Chelonia agassizii.
Eretmochelys squamosa.
Caretta olivacea.
Dermochelys schlegelii.

All of the foregoing genera except four (*Bipes*, *Ctenosaura*, *Sator*, and *Phyllodactylus*) range down the peninsula from beyond its border in the southwestern United States, and the species are mainly the same as those from the north or are more or less closely related to them. *Bipes*, the most marked of the two genera of reptiles peculiar to the peninsula, includes a single species known only from the cape district south of La Paz. *Bipes* belongs to a distinct family—Bipedidae—and is related to the ancient family *Amphisbaenidae*. Dr. Leonhard Stejneger informs me that he considers its presence at the southern end of the peninsula good evidence of the great age of that area. This is of special interest in view of the comparatively recent origin of the remainder of the vertebrate fauna. The nearest relative geographically of *Bipes* is the genus *Euchirotes* of the Mexican tableland. The nearest relatives of the new genus *Sator* are *Sceloporus* and *Uta*.

Ctenosaura, the well-known iguana, so abundant on the tropical west coast of Mexico, is represented in the cape district by one insular species. The curious genus *Sauromalus*, common in parts of the southwestern United States, ranges south to La Paz and is represented in Lower California by three species. *Phyllodactylus*, a genus of geckos, which is abundant on the tropical west coast of Mexico, is represented in the cape district by two species, one of

[1] Proc. Calif. Acad. Sci., 2d ser., V, pp. 77–162 with plates, 1895.

which (*P. tuberculosus*), is common on the coast of the Mexican mainland. Owing to its habit of commonly frequenting houses it is not improbable that this species may have been brought to Lower California in household effects from Mazatlan or other coast ports.

The distribution and relationships of the reptiles in Lower California are still so imperfectly known that considerable modification of the following summary is certain to result from future work. A limited number of species common to the southwestern United States are not known to extend their ranges south beyond the northern half of the peninsula. Of the 39 genera and 102 species and subspecies of reptiles known from the peninsula 32 genera and 59 species and subspecies have been taken in the cape district. Of these 38 appear to be peculiar to this area.

The species known in the cape district are named in the following list. Those marked with an asterisk (*) are peculiar to it. Those not so marked are widely ranging Lower Sonoran species from the north, except the gecko (*Phyllodactylus tuberculosus*), which is common on the opposite coast of the Mexican mainland.

Reptiles Known from the Cape District.

Phyllodactylus tuberculosus.
**Phyllodactylus unctus.*
**Ctenosaura hemilopha.*
**Ctenosaura insulana.*
**Dipsosaura dorsalis lucasensis.*
Crotaphytus copeii.
**Sauromalus interbrachialis.*
**Callisaurus carmenensis.*
**Callisaurus crinitus.*
Callisaurus draconoides.
**Callisaurus plasticus.*
Callisaurus ventralis ventralis.
**Uta mannophorus.*
Uta microscutata.
**Uta nigricauda.*
**Uta repens.*
**Uta squamata.*
Uta stansburiana elegans.
**Uta thalassina.*
**Sator angustus.*
**Sator grandævus.*
**Sceloporus licki.*
**Sceloporus lineatulus.*
Sceloporus zosteromus.
Phrynosoma coronatum.
**Gerrhonotus multi-carinatus.*
Anniella pulchra.
**Xantusia gilberti.*
**Verticaria caerulea.*
**Verticaria hyperythra hyperythra.*
Verticaria sericea.
**Cnemidophorus celeripes.*
**Cnemidophorus maximus.*
**Cnemidophorus rubidus.*
**Cnemidophorus vandenburghi.*
**Plestiodon skiltonianus lagunensis.*
**Bipes biporus.*
Siagonodon humilis.
**Lichanura trivirgata.*
**Coluber aurigulus.*
Coluber constrictor flaviventris.
Coluber lateralis.
Salvadora hexalepis.
Phyllorhynchus decurtatus.
**Pituophis vertebralis.*
**Lampropeltis boylii conjuncta.*
**Lampropeltis nitida.*
Rhinocheilus lecontei
Hypsiglena ochrorhynchus.
Chilomeniscus fasciatus.
**Chilomeniscus stramineus.*
**Natrix valida.*
Trimorphodon lyrophanes.
**Tantilla planiceps.*
Crotalus atrox.
**Crotalus enyo.*
**Crotalus lucasensis.*
Crotalus mitchellii.
**Pseudemys ornata nebulosa.*

Birds.

Following are lists of the genera of birds known from the peninsula, with notation of the number of species and subspecies. Of land birds there are 142 genera and 286 species and subspecies; and of water birds there are 100 genera and 142 species and subspecies.

Genera of Land Birds with Number of Species and Subspecies Known from Lower California.

Oreortyx	1	*Polyborus*	2	*Phalaenoptilus*	2
Lophortyx	2	*Pandion*	1	*Chordeiles*	3
Chloroenas	1	*Tyto*	1	*Nephoecetes*	1
Zenaidura	1	*Asio*	2	*Chaetura*	1
Melopelia	1	*Bubo*	3	*Aeronautes*	1
Chaemepelia	1	*Strix*	1	*Archilochus*	1
Scardafella	1	*Otus*	3	*Calypte*	2
Gymnogyps	1	*Speotyto*	1	*Selasphorus*	2
Cathartes	1	*Glaucidium*	1	*Basilinna*	1
Elanus	1	*Micropallas*	1	*Tyrannus*	3
Circus	1	*Crotophaga*	1	*Myiarchus*	2
Accipiter	2	*Geococcyx*	1	*Sayornis*	2
Parabuteo	1	*Coccyzus*	1	*Nuttallornis*	1
Buteo	5	*Streptoceryle*	1	*Myiochanes*	2
Archibuteo	1	*Chloroceryle*	1	*Empidonax*	6
Aquila	1	*Dryobates*	5	*Pyrocephalus*	1
Haliaeetus	1	*Sphyrapicus*	2	*Otocoris*	4
Hierofalco	1	*Balanosphyra*	2	*Cyanocitta*	1
Rhynchodon	1	*Centurus*	2	*Aphelocoma*	2
Tinnunculus	2	*Colaptes*	5	*Corvus*	1
Cerchneis	2	*Setochalcis*	1	*Nucifraga*	1

Genera of Land Birds with Number of Species and Subspecies Known from Lower California—Continued.

Cyanocephalus	1	*Guiraca*	1	*Anthus*	2
Molothrus	2	*Passerina*	2	*Cinclus*	1
Xanthocephalus	1	*Spiza*	1	*Oreoscoptes*	1
Agelaius	3	*Calamospiza*	1	*Mimus*	1
Sturnella	1	*Piranga*	2	*Dumetella*	1
Icterus	3	*Progne*	1	*Toxostoma*	7
Euphagus	2	*Petrochelidon*	1	*Heleodytes*	3
Carpodacus	6	*Hirundo*	1	*Salpinctes*	3
Loxia	1	*Iridoprocne*	1	*Catherpes*	1
Astragalinus	3	*Tachycineta*	2	*Thryomanes*	2
Spinus	1	*Riparia*	1	*Thryothorus*	1
Pooecetes	2	*Stelgidopteryx*	1	*Troglodytes*	1
Passerculus	6	*Bombycilla*	1	*Nannus*	1
Ammodramus	1	*Phainopepla*	1	*Telmatodytes*	2
Chondestes	1	*Lanius*	3	*Sitta*	4
Zonotrichia	4	*Vireosylva*	1	*Baeolophus*	2
Spizella	4	*Lanivireo*	2	*Penthestes*	1
Junco	5	*Vireo*	5	*Psaltriparus*	2
Amphispiza	3	*Mniotilta*	1	*Auriparus*	2
Aimophila	2	*Vermivora*	4	*Chamaea*	1
Melospiza	6	*Dendroica*	9	*Corthylio*	2
Passerella	1	*Seiurus*	1	*Polioptila*	4
Pipilo	6	*Geothlypis*	5	*Myadestes*	1
Oberholseria	1	*Icteria*	1	*Hylocichla*	6
Richmondena	1	*Wilsonia*	2	*Planesticus*	2
Pyrrhuloxia	1	*Setophaga*	1	*Ixoreus*	1
Hedymeles	1	*Motacilla*	1	*Sialia*	3

Genera of Water Birds with Number of Species and Subspecies Known from Lower California.

Aechmophorus	1	*Lophodytes*	1	*Porzana*	1
Colymbus	2	*Anas*	1	*Creciscus*	1
Podilymbus	1	*Chaulelasmus*	1	*Gallinula*	1
Gavia	2	*Mareca*	1	*Fulica*	1
Cerorhinca	1	*Nettion*	1	*Phalaropus*	1
Ptychoramphus	1	*Querquedula*	2	*Lobipes*	1
Brachyramphus	2	*Spatula*	1	*Steganopus*	1
Stercorarius	1	*Dafila*	1	*Recurvirostra*	1
Rissa	1	*Marila*	4	*Himantopus*	1
Larus	6	*Clangula*	1	*Gallinago*	1
Blasipus	1	*Charitonetta*	1	*Limnodromus*	1
Chroicocephalus	2	*Melanitta*	2	*Pisobia*	3
Xema	1	*Erismatura*	1	*Pelidna*	1
Gelochelidon	1	*Chen*	1	*Ereunetes*	1
Hydroprogne	1	*Anser*	1	*Calidris*	1
Thalasseus	2	*Branta*	2	*Limosa*	1
Sterna	2	*Dendrocygna*	1	*Vetola*	1
Sternula	1	*Ajaia*	1	*Totanus*	2
Chlidonias	1	*Guara*	1	*Tringa*	1
Phoebastria	2	*Plegadis*	1	*Catoptrophorus*	1
Diomedea	1	*Mycteria*	1	*Heteroscelus*	1
Fulmarus	1	*Botaurus*	1	*Actitis*	1
Ardenna	1	*Ixobrychus*	1	*Numenius*	2
Puffinus	3	*Ardea*	2	*Squatarola*	1
Thyellodroma	1	*Casmerodius*	1	*Pluvialis*	1
Halocyptena	1	*Egretta*	1	*Oxyechus*	1
Oceanodroma	4	*Dichromanassa*	1	*Charadrius*	2
Phaethon	1	*Hydranassa*	1	*Pagolla*	1
Scaeophaethon	1	*Florida*	1	*Eupoda*	1
Sula	4	*Butorides*	2	*Aphriza*	1
Phalacrocorax	4	*Nycticorax*	1	*Arenaria*	2
Pelecanus	2	*Nyctanassa*	1	*Haematopus*	2
Fregata	1	*Grus*	1		
Mergus	2	*Rallus*	3		

Mammals.

Following is a list of the 51 genera of mammals known from the peninsula, showing 166 species and subspecies.

GENERA OF LAND MAMMALS WITH NUMBER OF SPECIES AND SUBSPECIES KNOWN FROM LOWER CALIFORNIA.

Adocoileus	4	*Thomomys*	5	*Latax*	1
Antilocapra	1	*Dipodomys*	7	*Sorex*	3
Ovis	1	*Perodipus*	2	*Notiosorex*	1
Sciurus	1	*Perognathus*	19	*Scapanus*	1
Eutamias	2	*Lepus*	6	*Balantiopteryx*	1
Citellus	4	*Sylvilagus*	8	*Nycteris*	2
Ammospermophilus	3	*Felis*	2	*Dasypterus*	1
Castor	1	*Lynx*	2	*Mormoops*	1
Mus	2	*Canis*	5	*Otopterus*	1
Onychomys	2	*Urocyon*	2	*Chaeronycteris*	1
Peromyscus	20	*Vulpes*	2	*Natalus*	1
Sigmodon	1	*Ursus*	1	*Myotis*	6
Oryzomys	1	*Bassariscus*	3	*Pizonyx*	1
Reithrodontomys	3	*Procyon*	2	*Pipistrellus*	2
Neotoma	14	*Taxidea*	2	*Eptesicus*	2
Microtus	1	*Mephitis*	2	*Antrozous*	3
Fiber	1	*Spilogale*	3	*Nyctinomus*	3

A glance over the foregoing list of genera reveals the greatly preponderating northern origin of the mamalian fauna of Lower California, the small Mexican or tropical element being represented by the rice rat (*Oryzomys peninsulae*) and half a dozen bats, including *Balantiopteryx plicata*, *Mormoops megalophylla senicula*, *Chaeronycteris mexicana*, *Natalus mexicanus*, *Dasypterus ega xanthinus*, and *Nyctinomus depressus*. Some, at least, of these bats probably migrate in fall to the Mexican mainland, since we saw no trace of them in winter but were informed that they appear in considerable numbers in spring and summer.

SUBORDINATE FAUNAL DISTRICTS.

As indicated on the outline map (see Pl. 31), Lower California contains five natural faunal areas, here called "districts," which are partly independent of the general distribution of the life zones. Some of these areas lie within a single life zone, others in two or more. These areas are briefly characterized below and the lists of birds and mammals peculiar to each show they are strongly marked. They are probably characterized equally well by other groups of animal and plant life. The three northern areas are southern continuations of faunal areas occupying adjacent parts of southern California, thus extending the range of most of the characteristic species to both sides of the northern boundary. The most notable of the faunal areas of the peninsula is the cape district, which is here much extended beyond the previously recognized limits. Taking the areas in their sequence from north to south they stand as follows:

1. San Pedro Martir District.

This district covers a narrow belt about 175 miles long extending from the northern border a little east of south to Matomi, near the middle of the peninsula. It occupies the summits of the Sierra Juarez and San Pedro Martir Mountains, above about 4,000 to 4,500 feet on the west and above 4,500 to 5,500 feet on the east and includes all of the transition zone in the peninsula, with the upper part of the Upper Sonoran zone in this section. This area also is the only part of Lower California on which snow falls and in which there is a yellow pine forest. The entire area is mountainous with tremendous escarpments on its eastern border. It lies mainly between 4,000 and 9,000 feet altitude, but reaches the extreme elevation of over 10,000 feet on La Providencia Peak. The slopes above 9,000 feet are mainly rocky and barren. On the cooler upper slopes there is a slight infusion of Boreal species, and along its lower border the Upper Sonoran zone is strongly in evidence. The lists and zonal relationships of the species in this area are detailed below in the account of the transition zone with which it is so nearly coincident.

2. San Diegan District.

The San Diegan district occupies northwestern Lower California and like the preceding district forms the southern extension of an area which has been characterized as a faunal subdivision of southern California. It extends south of the California boundary from sea level up to an altitude of about 4,000 feet on the west slope of the Sierra Juarez and to over 4,500 feet on the same slope of the San Pedro Martir Mountains, with a southern extension to the mouth of El Rosario Arroyo on the coast, gradually narrowing beyond San Quintin to a point at its southern end. The surface of this area is mainly an irregular plateau varied with coastal mountains and scattered hills and ridges with small intervening valleys, and contains near its southern end the coastal plains of Hamalu and San Quintin. It is exposed to the cool, damp winds from the Pacific and more or less regular winter rains. This area lies almost wholly within the Upper Sonoran life zone, but in places back from the seacoast, as in Trinidad Valley and the southern end of San Rafael Valley, there is an admixture of the Lower Sonoran zone, which becomes especially marked in the southern part of the area. Further notes on this area, with lists of some of the most characteristic plants, reptiles, birds, and mammals, are given below in the account of the Upper Sonoran life zone.

3. Colorado Desert District.

The Colorado Desert district is the extension southward across the border of southeastern California of the Colorado Desert. It covers all northeastern Lower California between sea level and an altitude of from nearly 4,500 feet on the Sierra Juarez to 5,500 feet or over on the bare east slope of the San Pedro Martir Mountains. To the southward of these mountains it occupies the gulf slope from the shore to the tops of the bordering main range. Its southern limit is about Angeles Bay. From Matomi, at the southern end of the San Pedro Martir Mountains, and Point San Fermin southward it forms a narrowing strip east of the main mountain chain which here more closely parallels the coast. It extends westward about the southern end of the San Pedro Martir Mountains and along the southwestern base of these mountains where it meets the San Diegan district.

In the north it is mainly a plain containing the delta and flood plains of the Colorado River, varied by the Cocopah, Sierra Pinta, and other desert mountains. Farther south the plain is broken by the Sierra San Felipe, Sierra Santa Clara, and other barren hills and mountains with intervening plains or valleys. Water is extremely scarce and occurs mainly in natural tanks or tinajas along the base of the desert ranges, and as small streams in the lower part of the canyons along the east base of the main Juarez-San Pedro Martir Range.

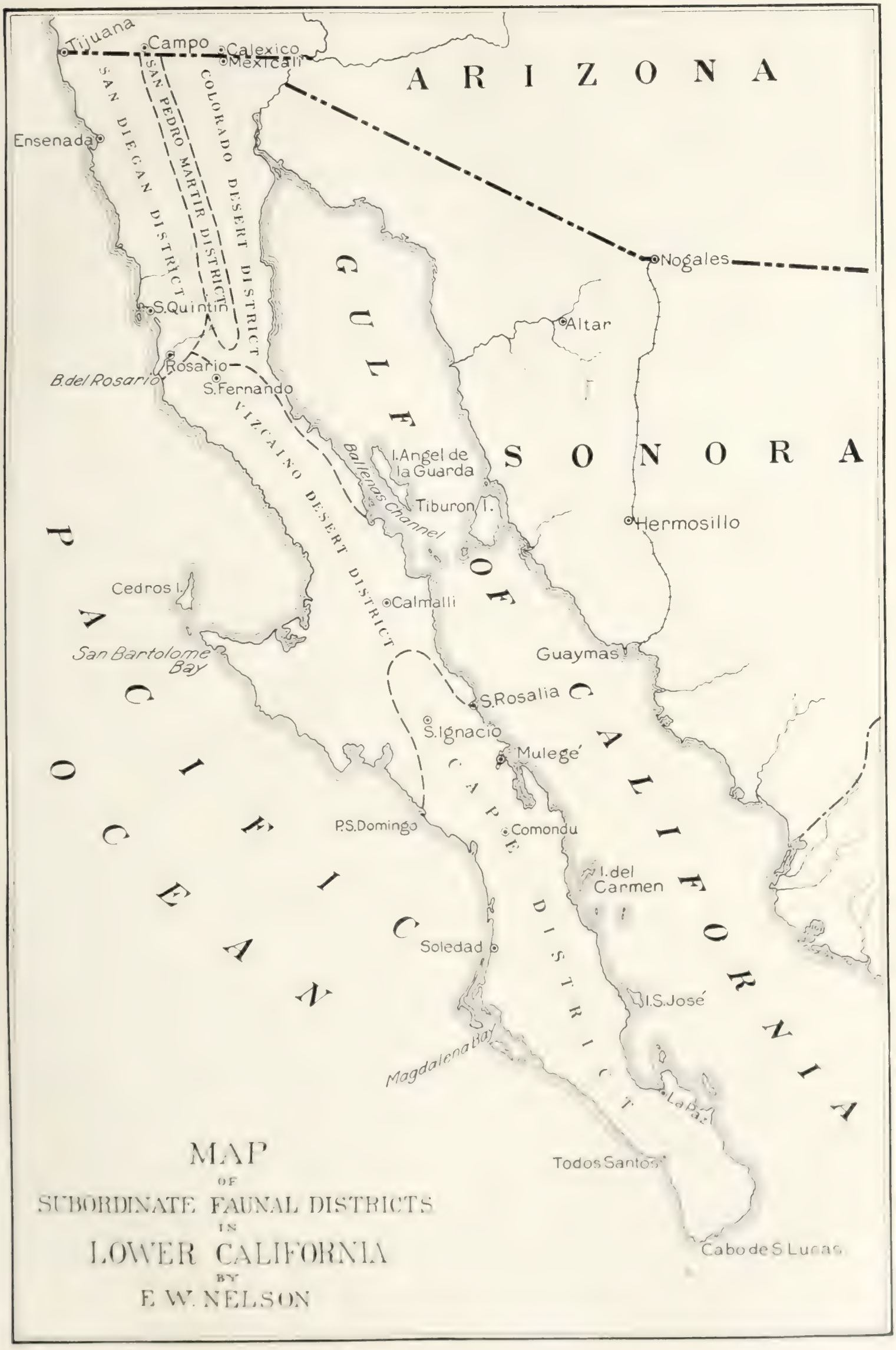
Its plants are largely those of the Colorado Desert in California, but along the east base of the San Pedro Martir Mountains and south from near San Felipe Bay numerous other species come in. This desert area lies wholly within the Lower Sonoran Zone with a tinge of a subtropical flora along the gulf coast. The characteristic birds and mammals of this area are listed beyond under the heading of the Lower Sonoran zone.

CHARACTERISTIC PLANTS OF THE COLORADO DESERT DISTRICT OF LOWER CALIFORNIA.

Ephedra trifurca.	*Cercidium torreyanum.*	*Parkinsonia aculeata.*
Acacia greggi.	*Encelia farinosa.*	*Parkinsonia microphylla.*
Prosopis glandulosa.	*Hymenoclea monogyra.*	*Isomeris arborea.*
Covillea glutinosa.	*Pluchea sericea.*	*Koeberlinia spinosa.*
Fouquieria splendens.	*Chilopsis linearis.*	*Pachycereus pringlei.*

4. Vizcaino Desert District.

This district occupies the middle section of the peninsula, its northern boundary being formed by the southern border of the San Diegan and Colorado Desert districts. It extends thence southward to include the northern and northwestern borders of the great lava plateau and southward along the coast for some distance on both sides. On the east of the lava plateau


Tijuana
Campo
Calexico
Mexicali
ARIZONA
SAN DIEGAN DISTRICT
SAN PEDRO MARTIR DISTRICT
COLORADO DESERT DISTRICT
Ensenada
Nogales
S.Quintin
Altar
Rosario
B.del Rosario
S.Fernando
VIZCAINO DESERT DISTRICT
GULF OF
SONORA
I.Angel de la Guarda
Ballenas Channel
Tiburon I.
Hermosillo
PACIFIC OCEAN
Cedros I.
Calmalli
San Bartolome Bay
Guaymas
S.Rosalia
CALIFORNIA
S.Ignacio
Mulegé
CAPE DISTRICT
P.S.Domingo
Comondu
I.del Carmen
Soledad
I.S.José
Magdalena Bay
La Paz
Todos Santos
Cabo de S Lucas
MAP
OF
SUBORDINATE FAUNAL DISTRICTS
IN
LOWER CALIFORNIA
BY
E W. NELSON

the extension of the Vizcaino district is in the form of a narrow belt lying between the main mountain chain and the coast extending to the vicinity of Santa Rosalia. On the Pacific side the southern extension is in the form of a narrow wedge terminating near Santo Domingo Point in about latitude 26° 20′. This district includes nearly all of the table-lands characterized by granite formation from their northern border south to the northern end of the volcanic plateau beyond Calmalli. It also includes all of the Vizcaino Desert, most of which is a broad coastal plain with a low table-land on its eastern and northern borders. The plateau country to the north is broken by scattered mountains, low ridges, and groups of granite mountains separated by plains which in some places take the form of shallow troughlike or basin-shaped valleys.

The Vizcaino district is practically all within the Lower Sonoran zone but has a mixture of arid tropical plants, especially on the borders of the lava plateau and along the gulf coast.

A few of the higher mountain tops extend within Upper Sonoran climatic conditions, although the area at these high elevations is so limited and so extremely barren that they appear to possess little or no life to characterize the zone.

The Vizcaino district is notable for its extraordinary development of desert vegetation. Two of the most remarkable and characteristic plants of Lower California are limited mainly to its confines. The first, *Idria columnaris*, known locally as the "cirio," forms scattered, polelike forests over most of the interior table-lands from near Calmalli north to beyond San Fernando, the species ranging but little beyond these limits. (See Pl. 29, Fig. 1.) The second, *Veatchia discolor*, the elephant wood, is characteristic of this region but has a somewhat wider range than *Idria*. (See Pl. 28, Fig. 2.) In addition a large part of the interior granitic table-lands within this district is covered with an extraordinarily large and vigorous growth of giant and other cactuses, yuccas, agaves, palo verdes, fouquierias, and numerous other desert trees and shrubs which over great areas form low thorny forests or jungles. The plants of this area have been so little studied that besides *Idria* and *Veatchia* it is difficult to list the peculiar species, although they must be numerous.

As in the case of the plants, the reptiles of this district are little known and the species so far taken within its limits appear to range widely in adjacent regions, most of them belonging also in the Colorado Desert district or to the cape district. The most characteristic species of birds and mammals are listed beyond in the account of the Lower Sonoran zone.

5. Cape District.

The cape district is the southernmost of the subordinate faunal areas of Lower California.[1] Its strikingly localized fauna and flora have attracted the attention of naturalists since about 1861, when they were first made known through the collections of John Xantus. As a result it has been visited by numerous naturalists, and has contributed more material and had more published concerning it than any other section of the peninsula.

The mountainous southeastern end of the peninsula south of La Paz is separated from the mountains farther north by a broad low pass extending from the head of La Paz Bay to the Pacific. The islandlike character of this southern area and the fact that the peculiar flora and and fauna of southern Lower California is most strongly marked there has led Bryant, Brandegee, Brewster, and other writers to define it as the "Cape Region." With the knowledge of the distribution of species now available, however, it becomes necessary to extend its limits northward to include all of the peninsula near Santa Rosalia on the gulf coast and thence to near the northern boundary of the lava plateau in the middle of the peninsula and southeasterly to the Pacific coast in about latitude 26° 20′. The cape district as thus defined is composed of two sections: (1) A northern one, north of the pass at La Paz Bay, which comprises the Magdalena Plain along the Pacific coast and the interior lava capped plateau, rising to include

[1] This area has commonly been known as the "Cape Region," but the use of the term "region" in a faunal sense for so limited an area appears inappropriate, and I have substituted the word district for this and other similar faunal areas in the peninsula.

the Sierra de la Giganta along the gulf coast; (2) that part of the peninsula south of La Paz Bay, which is the area formerly considered to constitute all of the "Cape Region" is mainly occupied by granite, limestone, and volcanic mountains. In the northern section of the cape district taking in most of the lava-covered plateau with the main range of mountains along the Gulf coast, including the Sierra San Francisco, Sierra Santa Lucia, and Sierra de la Giganta, rises in a few places to altitudes of over 5,000 feet, but averages from 2,000 to 4,000 feet and slopes westward across the plateau to the Magdalena Plain and the Vizcaino Desert. South of La Paz some of the mountain peaks of the Sierra Victoria rise to elevations of from 6,000 to 8,000 feet in the form of sharp granite points, but the main range averages from 3,500 to 6,000 feet altitude. The Sierra Victoria has the most regular summer rains of any part of the peninsula and in consequence has comparatively abundant vegetation, especially on its eastern flanks and summit.

In climatic conditions the coastal lowlands, foothills, and lower mountains up to 4,000 feet or more of the cape district are Arid Tropical, but the plants are a mixture of Arid Tropical and Lower Sonoran species. The reptiles, birds, and mammals are mainly Lower Sonoran with a small tropical element, the preponderance of Lower Sonoran species of animals in this being due to the fact that the only connection with the rest of the continent by land for a great period has been through California on the north. The foothills have a mixture of Arid Tropical and Lower Sonoran species up to over 2,000 feet, the upper border only becoming more strongly Lower Sonoran, which thus forms a narrow belt of this zone from 2,000 to about 4,000 feet. From about 4,000 feet to the summit the mountains are Upper Sonoran. Heretofore no attempt appears to have been made to separate what has been termed the "Fauna of the Cape Region" into its zonal elements. It should here be stated, however, that it is difficult to recognize more than two life zones in the cape district, since, owing to its limited area and prevalence of Lower Sonoran species, the Arid Tropical and Lower Sonoran zones are almost inextricably interwoven. The reptilian fauna of the cape district is much more strongly marked than that of any other part of the peninsula, but through lack of sufficient collections and information on distribution I have been unable to separate the species zonally, as in the case of the birds and mammals. The reptiles characteristic of the cape district are listed and discussed under the general treatment of the reptilian fauna of the peninsula (p. 115.).

A number of species of birds, trees, and shrubs occur in Lower California only in the mountains of the cape district south of La Paz, and some of these are peculiar to that section, a fact which emphasizes the islandlike character of this area. As stated elsewhere, there is no doubt that the sea once separated this extremity of the peninsula from the main body at the point where the low pass now exists opposite La Paz Bay, and during this period of isolation many of the local species probably originated. Lists are subjoined of the birds and mammals of the cape district subdivided according to their zonal distribution in this area.

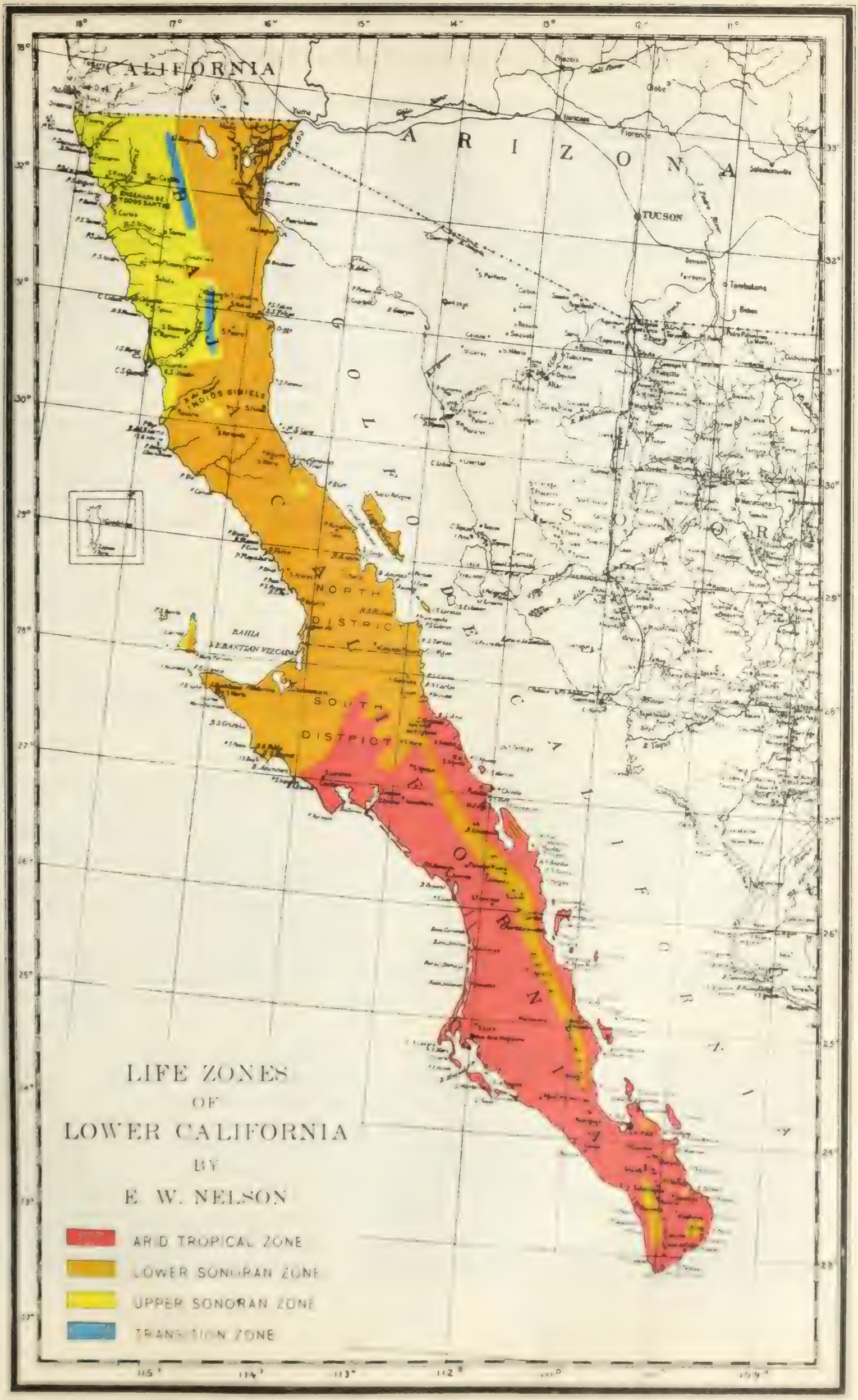
Characteristic Birds of the Cape District of Lower California Listed According to Zonal Distribution.

ARID TROPICAL.

Ardea herodias sanctilucae.	*Polyborus cheriway audubóni.*	*Passerina versicolor pulchra.*
Egretta thula brewsteri.	*Crotophaga sulcirostris.*	*Melospiza melodia rivularis.*
Butorides virescens frazari.	*Pyrocephalus rubinus mexicanus.*	*Dendroica erithachorides castaneiceps.*
Rallus beldingi.	*Richmondena cardinalis ignea.*	*Geothlypis beldingi beldingi.*
Chaemepelia passerina pallescens.	*Pyrrhuloxia sinuata peninsulae.*	

ARID TROPICAL AND LOWER SONORAN.

Cerchneis sparveria peninsularis.	*Myiarchus cinerascens pertinax.*	*Heleodytes brunneicapillus affinis.*
Otus asio xantusi.	*Aphelocoma californica hypoleuca.*	*Auriparus flaviceps lamprocephalus.*
Dryobates scalaris lucasanus.	*Carpodacus mexicanus ruberrimus.*	*Polioptila plumbea plumbea.*
Centurus uropygialis brewsteri.	*Pipilo fuscus albigula.*	
Colaptes chrysoides chrysoides.	*Toxostoma cinerea cinerea.*	


CALIFORNIA
ARIZONA
SONORA
TUCSON
GULF OF CALIFORNIA
NORTH DISTRICT
SOUTH DISTRICT
BAHIA SEBASTIAN VIZCAINO
ENSENADA DE TODOS SANTOS
INDIOS GIGUELS
LIFE ZONES
OF
LOWER CALIFORNIA
BY
E. W. NELSON
ARID TROPICAL ZONE
LOWER SONORAN ZONE
UPPER SONORAN ZONE
TRANSITION ZONE

UPPER SONORAN.

Chloroenas fasciata vioscae.	*Junco bairdi.*	*Vireo huttoni cognatus.*
Glaucidium gnoma hoskinsi.	*Aimophila ruficeps sororia.*	*Sitta carolinensis lagunae.*
Balanosphyra formicivora angustifrons.	*Pipilo maculatus magnirostris.*	*Baeolophus inornatus cineraceus.*
Basilinna xantusi.	*Tachycineta thalassina brachyptera.*	*Psaltriparus minimus grindae.*
Myiochanes richardsonii peninsulae.	*Lanivireo solitarius lucasanus.*	*Planesticus confinis.*

CHARACTERISTIC MAMMALS OF THE CAPE DISTRICT, LISTED ACCORDING TO ZONAL DISTRIBUTION.

ARID TROPICAL AND LOWER SONORAN.

Citellus atricapillus.	*Lepus californicus xanti.*	*Natalus mexicanus.*
Ammospermophilus leucurus peninsulae.	*Sylvilagus auduboni confinis.*	*Myotis volans.*
	Sylvilagus bachmani peninsularis.	*Myotis peninsularis.*
Peromyscus maniculatus magdalenae.	*Vulpes macrotis devia.*	*Myotis micronyx.*
Peromyscus eremicus eva.	*Bassariscus astutus palmarius.*	*Pizonyx vivesi.*
Oryzomys peninsulae.	*Procyon psora.*	*Pipistrellus hesperus australis.*
Neotoma intermedia pretiosa.	*Taxidea taxus infusca.*	*Eptesicus fuscus peninsulae.*
Neotoma intermedia arenacea.	*Spilogale microdon.*	*Dasypterus ega xanthinus.*
Thomomys bottae anitae.	*Spilogale lucasana.*	*Antrozous pallidus minor.*
Dipodomys merriami melanurus.	*Balantiopteryx plicata.*	*Nyctinomus depressus.*
Perognathus baileyi rudinoris.	*Mormoops megalophylla senicula.*	
Perognathus spinatus peninsulae.	*Chaeronycteris mexicana.*	

UPPER SONORAN.

Ovis canadensis.	*Thomomys bottae alticola.*	*Sorex lagunae.*
Peromyscus truei lagunae.		

MAMMALS RANGING THROUGHOUT THE FOREGOING ZONAL AREAS.

[Not restricted to the Cape District.]

Odocoileus hemionus peninsulae.	*Neotoma intermedia intermedia.*	*Canis peninsulae.*
Peromyscus maniculatus coolidgei.	*Lynx ruffus californicus.*	*Urocyon cinereoargenteus californicus.*

LIFE ZONES.

Lower California contains four life zones and a trace of a fifth, as follows: The Arid Tropical, Lower Sonoran, Upper Sonoran, Transition, and Canadian. Of these the Lower Sonoran is by far the most important, covering about three-fourths of the entire land area and extending from one coast to the other and practically the entire length of the Peninsula. It contains the majority of the characteristic and conspicuous plants and animals. The great preponderance of this zone led Dr. Merriam to make the general statement that "Lower California is a subdivision of the Arid Lower Sonoran zone."[1]

It should be stated here that the islands along both coasts agree in zonal characteristics with the adjacent mainland except in a few instances which are noted.[2] These life zones, taken in their sequence, are characterized as follows:

Arid Tropical Zone.

The southern end of Lower California lies within the Tropics and, having an extremely dry climate, naturally belongs to the Arid Tropical zone. This zone in the peninsula, however, is not confined to that section south of the Tropic of Cancer but extends along the gulf coast from the shore back over the foothills of the adjacent mountains, and northward to San Lucas at the northern end of Llano de San Bruno. Thence it leaves the shore but continues northward along the base of the mountains some distance beyond the Tres Virgines Peaks. In addition, all of the gulf islands north to opposite San Lucas are also

[1] Proc. Biol. Soc. Washington, VII, p. 29, April, 1892.

[2] Dr. Paul Bartsch informs me that the littoral marine invertebrate fauna (especially the mollusks) of Lower California belong to two subdivisions. The first extends along the west coast from near Santa Barbara, Calif., to near Cape San Lucas. The other includes both coasts of the Gulf of California, and extends thence southward to Guatemala and is known as the "Mazatlanic Fauna," a subdivision of the Tropicalian.

within this range. From La Paz Bay to Cape San Lucas the Arid Tropical zone covers all of the peninsula up to about 2,000 feet on the north and east slopes, and 2,500 feet on south and west slopes of the foothills and up the canyons cutting into the mountain ranges. This leaves only a limited Upper and Lower Sonoran area capping the northern part of the Sierra de la Victoria. This Arid Tropical area extends through the broad low pass to the west and south of La Paz to the Pacific coast and thence in a broad belt occupying all of the Magdalena Plain and adjacent lower slopes of the mountains northward to the southern end of the Vizcaino Desert about Ballenas Bay and inland along the lower slopes and deep canyons of the interior plateau to include San Ignacio and Natividad Canyon, northwest of San Ignacio. The Arid Tropical area gradually descends to the northward from about 2,500 feet in the southern end of the peninsula to less than 1,000 feet near San Ignacio. The exact definition of this zone and its relation to the Lower Sonoran zone is extremely difficult owing to the strong mixture of Lower Sonoran species throughout the Arid Tropical area, and the extension of numerous Arid Tropical plants well within the Lower Sonoran lines.

Above an altitude of about 1,000 feet, south of La Paz, Arid Tropical plants become conspicuously less numerous, and Lower Sonoran species increase. The few tropical birds occurring in the peninsula all range below 2,000 feet. The Lower Sonoran species of birds and mammals range in equal abundance from sea level up through both Arid Tropical and Lower Sonoran zones, thus adding to the confusion of the upper limit of the Arid Tropical zone of this region and rendering its definition possible only through the distribution of its plant life. Immediately north of La Paz Bay a similar relationship exists between the zones, the Upper Sonoran zone being represented on the upper slopes of Mechudo Peak, but, as already stated, the altitude of the upper limit of the Arid Tropical gradually decreases northward. The limit of this last-named zone extends farther north along the basal slopes of the mountains and canyons of the great lava plateau northwest of San Ignacio than along the coast. It will be noted that the northern extension of the Arid Tropical zone is nearly coincident with the northern limits of the cape district, as it is here termed.

As noted elsewhere, the tropical element in the vertebrate animal life of Lower California, practically limited to this district, is surprisingly small and is insufficient in quantity and of too doubtful origin to prove any former land connection between the peninsula and the Mexican mainland within the period in which the present species have existed.

Plants of Arid Tropical Zone.—As might be expected, the number of Arid Tropical plants both of species and individuals decrease gradually from the extreme southern end of the peninsula northward. By the overlapping common to adjacent zonal areas a number of Arid Tropical species range far north of the limits of the Arid Tropical zone here given.

Within this zone in Lower California the banana, coconut, and date palms are cultivated. The tamarind (*Tamarindus indica*) and the guamuchli (*Pithecolobium dulce*) have also been introduced and have escaped from cultivation in some places south of La Paz Bay. Among other notable Arid Tropical plants in this zone of the peninsula are *Ficus palmeri*, *Lysiloma microphylla* and *L. candida*, *Mimosa xanti*, several species of *Jatropha*, *Haematoxylon boreale*, *Xanthoxylon pterota*, two species of *Lantana*, several species of *Elaphrium*, *Manihot chlorosticta*, *Ibervillea sonorae*, and numerous cactuses including the extraordinary *Lemaireocereus eruca*, several opuntias, and the giant species *Pachycereus pecten-aboriginum* and *P. calvus*. The foregoing covers only some of the more important species and might be considerably extended.

It is interesting to note that a number of species of plants characteristic of the Arid Tropical parts of southern Lower California occur also in the arid subtropical coastal belt of southern Texas. Among these are *Xanthoxylon pterota*, *Lantana camara*, *Brayodendron texanum*, *Karwinskia humboldtiana*, and *Vachellia farnesiana*.

The tropical element in the plant life of this zone evidently originated on the coastal plains and foothill slopes of that part of the Mexican mainland lying directly eastward across the Gulf of California.

PLANTS CHARACTERIZING THE ARID TROPICAL ZONE IN LOWER CALIFORNIA.

[Species marked with an asterisk (*) occur also on the Mexican mainland.]

Roccella sp. (?)
**Cocos nucifera* (introduced).
Phoenix dactylifera (introduced).
Ficus palmeri.
Schoepfia californica.
Antignon leptopus.
Celosia floribunda.
Iresine alternifolia.
Phaulothamnus spinescens.
Steganosperma halimifolia.
**Atamisquaea emarginata.*
**Forchammeria watsoni.*
Acacia flexicaulis.
Albizzia occidentalis.
Lysiloma microphylla.
Lysiloma candida.
Mimosa purpurascens.
Mimosa xanti.
**Pithecolobium dulce* (introduced).
Prosopis palmeri.
**Vachellia farnesiana.*
Caesalpinia placida.
Caesalpinia mexicana californica.
Cassia confinis.
Cassia occidentalis.
Cassia articulata.
Cassia goldmani.
Cercidium peninsulare.
Haematoxylon boreale.
**Tamarindus indica* (introduced).
Erythrina purpusi.
Esenbeckia flava.
**Xanthoxylon pterota.*
Elaphrium rhoifolium.
Elaphrium odoratum.
Elaphrium cerasifolium.
Elaphrium epinnatum.
Elaphrium filicifolium.
Elaphrium goldmani.
Malpighia diversifolia.
**Mascagnia macroptera.*
Argithamnia brandegei.
Croton magdalenae.
Euphorbia californica.
Euphorbia xanti.
**Jatropha canescens.*
**Jatropha cordata.*
Manihot chlorosticta.
**Sebastiana bilocularis.*
Tapirira edulis.
Maytenus phyllanthoides.
**Dodonaea viscosa.*
Colubrina glabra.
**Karwinskia humboldtiana.*
Abutilon californicum.
Abutilon palmeri.
Gossypium davidsoni.
Gossypium harknessi.
**Melochia tomentosa.*
**Turnera humifusa.*
Echinocactus rectospinus.
Echinocactus falconeri.
Echinocactus digueti.
**Lemaireocereus thurberi.*
Lemaireocereus gummosus.
Lemaireocereus eruca.
Lophocereus australis.
Mammillaria roseana.
Opuntia tapona.
Opuntia comonduensis.
**Pachycereus pecten-aboriginum.*
Pereskiopsis brandegeei.
**Wilcoxia striata.*
**Rhizophora mangle.*
**Conocarpus erecta.*
Gongylocarpus fruticulosus.
Hauya arborea.
**Brayodendron texanum.*
**Plumiera mexicana.*
Vallesia dichotoma.
**Ipomoea pes-caprae.*
Jacquemontia abutiloides.
**Duranta plumieri.*
**Lantana camara.*
**Lantana involucrata.*
Lippia barbata.
Lippia formosa.
**Lippia palmeri.*
Mesosphaerum insulare.
Mesosphaerum laniflorum.
Mesosphaerum palmeri.
**Crescentia cujete.*
Beloperone purpusi.
Beloperone californica.
Justicia insolita.
Justicia palmeri.
Ruellia sp.
**Bourreria sonorae.*
**Chiococca racemosa.*
**Ibervillea sonorae.*
Alvordia fruticosa.
Bebbia atriplicifolia.
Eupatorium peninsulare.
Palafoxia arenaria.
Porophyllum confertum.

Reptiles of Arid Tropical Zone.—The only reptiles in the southern end of Lower California which appear to have originated on the tropical lowlands of the opposite shore of Mexico are a species of iguana (*Ctenosaura hemilopha*) and two species of geckos (*Phyllodactylus tuberculosus* and *P. unctus*).

Birds of Arid Tropical Zone.—Of the large number of species in the land-bird fauna of the peninsula only the nine listed below probably originated across the gulf on the mainland coast of Mexico.

Polyborus cheriway audubonì, resident throughout the year.
Chaemepelia passerina pallescens, resident throughout the year.
Crotophaga sulcirostris, resident in summer only(?).
Basilinna xantusi (not tropical), resident throughout the year.
Richmondena cardinalis ignea, resident throughout the year.
Pyrrhuloxia sinuata peninsulae, resident throughout the year.
Passerina versicolor pulchra, resident in summer only(?).
Dendroica erithachorides castaneiceps, resident throughout the year.
Geothlypis beldingi beldingi, resident throughout the year.

All of these species except *Crotophaga sulcirostris* and *Passerina versicolor pulchra* are permanent residents in the cape district. These two exceptions are well-known summer residents, but from November to February, 1905–6, we saw not a single individual of either, and I am inclined to believe that they migrate in fall to the mainland across the gulf.

Of the Mexican mainland element in the bird fauna of the cape district, *Chaemepelia passerina pallescens*, *Crotophaga sulcirostris*, *Passerina versicolor pulchra*, and *Dendroica erithachorides castaneiceps* belong to the tropical lowlands on both sides of the gulf, the specimens from Lower California being indistinguishable from those of the mainland. *Richmondena cardinalis ignea* and *Pyrrhuloxia sinuata peninsulae* are fairly well-marked local subspecies peculiar to the cape district but represented on the coastal plain across the gulf by closely related forms. *Geothylpis beldingi* belongs to a group of large closely related yellowthroats common in marshes on the Mexican tableland.

The birds that from their distribution near sea level or at low elevations may be said to characterize the Arid Tropical zone of Lower California, and to distinguish it from the adjoining and overlapping Lower Sonoran zone are:

Ardea herodias sancti-lucae.
Egretta thula brewsteri.
Butorides virescens frazari.
Rallus beldingi.
Chaemepelia passerina pallescens.
Polyborus cheriway auduboni.
Crotophaga sulcirostris.
Pyrocephalus rubinus mexicanus.
Richmondena cardinalis ignea.
Pyrrhuloxia sinuata peninsulae.
Passerina versicolor pulchra.
Dendroica erithachorides castaneiceps.
Geothlypis beldingi beldingi.
Geothlypis beldingi goldmani.

It will be noted that the foregoing list contains several species and subspecies which also range north in the Lower Sonoran zone of Sonora and Arizona, and others which are represented there by closely related subspecies, thus showing how slightly the really tropical element is represented in Lower California.

Mammals of Arid Tropical Zone.—With the exception of a few bats the only representative of the tropical mammal fauna of the Mexican coast is a species of rice mouse (*Oryzomys peninsulae*), the distribution of which appears to be limited to the single small marsh about the lagoon formed by the mouth of the San Jose River back of the landing place on the shore at San Jose del Cabo, where it may readily have been introduced in shipments of bananas or other farm products from Mazatlan or elsewhere along the mainland coast, where a related species is plentiful.

Of the bats known from Lower California the following seven species appear to have come from the Mexican mainland:

Balantiopteryx plicata.
Mormoops megalophylla senicula.
Chaeronycteris mexicana.
Natalus mexicanus.
Dasypterus ega xanthinus.
Nyctinomus depressus.
Pizonyx vivesi.

Of these, *Balantiopteryx plicata*, *Natalus mexicanus*, and *Dasypterus ega xanthinus* may be classed as characteristic of the Tropical life zone. The others range at least well through the Lower Sonoran zone.

Lower Sonoran Zone.

The Lower Sonoran life zone predominates in Lower California and covers approximately three-fourths of the total land area of the peninsula. It includes practically all of the Colorado and Vizcaino Desert districts and a large part of the cape district. In the interior it extends from the northern border, near the delta of the Colorado, southeasterly nearly to Cape San Lucas. It borders the gulf coast south to about Santa Rosalia, where it merges into the Arid Tropical zone. Here, in the middle of the peninsula, the Lower Sonoran crosses to the west side and borders the Pacific coast from the northern edge of the Arid Tropical zone, about latitude 26° 20′, north to about El Rosario River, where it meets the southern border of the Upper Sonoran area which occupies the northwestern part of the peninsula. In the northeastern and middle sections of the peninsula the Lower Sonoran zone extends from sea level up to from 4,000 to 4,500 feet, thus covering most of the desert mountain ranges of this region, including practically all of the Cocopah, San Felipe, Santa Clara, Santa Lucia, Vizcaino, and other ranges. Parts of the desert ranges and peaks rising more than 4,000 feet above sea level are commonly within the Upper Sonoran climatic conditions, but these areas are so limited that they possess but few if any of the representatives of animal and plant life characterizing that zone. On the east side of the

Sierra Juarez-San Pedro Martir Range the Lower Sonoran zone extends to about 4,000 feet and even higher on hot southerly slopes.

The Lower Sonoran zone crosses the high Sierra Juarez-San Pedro Martir Range through San Matias Pass and spreads over all the bottom of Trinidad Valley. A number of Lower Sonoran plants, birds, and mammals range north from this valley across Alamo Plain to the southern end of San Rafael Valley. There is another Lower Sonoran strip at the west base of the southern end of the San Pedro Martir Mountains extending south from San Antonio ranch, from which the coastal mountains immediately to the west cut off the cool damp coast winds.

From the northern limit of the Arid Tropical zone south to the end of the peninsula the Lower Sonoran zone lies inland and its lower limit gradually rises until in the section between La Paz and Cape San Lucas it is about 2,000 to 2,500 feet above sea level. The zone extends thence up on the mountain slopes to an altitude of about 4,500 feet, where it is replaced by the Upper Sonoran cap on the higher mountains. Owing to the northern origin of the great majority of the reptiles, birds, and mammals of Lower California, the Lower Sonoran element in the fauna, and to a considerable but smaller extent the same element in the flora, spreads throughout the Arid Tropical zone of the peninsula and thoroughly dilutes it. On the other hand, many of the Arid Tropical plants range up well into the Lower Sonoran zone, especially along the gulf coast. The Lower Sonoran zone is strongly defined throughout its extent north of the northern limit of the Arid Tropical zone.

It will be noticed in the subjoined lists that the Lower Sonoran zone of this region is characterized by most of the same species, or close relatives, of the plants, birds, and mammals notable in the same zone in southeastern California and southern Arizona. Numerous species and genera of cactuses, and the yuccas, agaves, creosote bushes (*Covillea*), mesquites, paloverde (*Parkinsonia*), and *Fouquieria* are especially prominent. With these such peculiar local species as the strange cirio (*Idria columnaris*) and elephant wood (*Pachycormus discolor*) give the landscapes of the middle region a strange individuality.

The coastal islands in the northern half of the gulf are entirely Lower Sonoran, but from Santa Rosalia southward are largely Arid Tropical in climate, although they are mainly occupied by Lower Sonoran species of plants, birds, and mammals. On the Pacific coast Cedros Island is Upper Sonoran on its northern and western slopes, but appears to be Lower Sonoran on sheltered parts of its southern end. Both Margarita and Magdalena Islands, while close to the Arid Tropical shore belt, are intermediate between this and the Lower Sonoran zone and are occupied by a mixture of Arid Tropical and Lower Sonoran species.

The following lists contain the most characteristic species of this zone. Owing to the division of the peninsula into subordinate faunal areas the bird and mammal lists are subdivided to show the distribution in different districts. The distribution of the plants is not sufficiently well known to subdivide them in the same way, but a short list is given of species characteristic of this zone in the cape district.

Plants of Lower Sonora Zone.—The following list contains a few of the species characterizing the Lower Sonoran zone in Lower California.

PLANTS CHARACTERIZING THE LOWER SONORAN ZONE IN LOWER CALIFORNIA.

[Species marked with an asterisk (*) occur also in California, and those marked with a dagger (†) occur also on the Mexican mainland.]

†**Ephedra trifurca.*
Erythea armata.
Erythea brandegeei.
**Nolina bigelovii.*
Yucca valida.
Agave cerulata.
Agave aurea.
Agave consociata.
Agave nelsoni.
Agave promontorii.
Agave vexans.
Agave goldmaniana.
Quercus brandegei.
Quercus idonea.
Eriogonum elongatum.
Eriogonum orcuttianum.
Eriogonum trichopodum.
†*Atriplex linearis.*
Hesperonia californica.
Quamoclidion triflorum.
**Isomeris arborea.*
Wislizenia palmeri.
**Acacia greggi.*
Prosopis palmeri.
†**Prosopis glandulosa.*
†**Prosopis odorata.*
Cassia purpusi.
†**Cercidium torreyanum.*
Hoffmanseggia microphylla.
†**Parkinsonia aculeata.*
†**Parkinsonia microphylla.*
†**Olneya tesota.*
†**Parosela spinosa.*

Plants Characterizing the Lower Sonoran Zone in Lower California—Continued.

†**Covillea glutinosa.*	*Fouquieria peninsularis.*	*Salvia californica.*
Elaphrium macdougalii.	*Idria columnaris.*	**Chilopsis linearis.*
Acalypha californica.	*Koeberlinia spinosa.*	†*Hymenoclea monogyra.*
Euphorbia tomentulosa.	*Echinocereus brandegeei.*	**Chrysoma palmeri.*
Pedilanthus macrocarpus.	†*Lophocereus schottii.*	*Encelia farinosa.*
†**Simmondsia californica.*	*Opuntia clavellina.*	**Lepidospartum squamatum.*
Pachycormus discolor.	†*Pachycereus pringlei.*	†*Peucephyllum schottii.*
Viscainoa geniculata.	*Cordia watsoni.*	†**Pluchea sericea.*
*†*Fouquieria splendens.*	* *Mesosphaerum emoryi.*	*Porophyllum gracile.*

A Few of the Plants Characterizing the Lower Sonoran Zone in the Cape District.

Quercus idonea.	*Agave promontorii.*	*Pedilanthus macrocarpus.*
Quercus brandegeei.	*Agave vexans.*	*Fouquieria peninsularis.*
Erythea brandegeei.	*Quamoclidion triflorum.*	*Opuntia clavellina.*
Yucca valida.	*Prosopis palmeri.*	
Agave aurea.	*Jatropha spathulata.*	

Reptiles of Lower Sonoran Zone.—The reptile fauna of the Lower Sonoran zone is very closely like that of the same zone in southeastern California, as shown by the imperfect list given below. Others undoubtedly belong in this list, but lack of definite information concerning their distribution prevents their inclusion.

Coleonyx variegatus.	*Callisaurus ventralis ventralis.*	*Cnemidophorus bartolomas.*
Dipsosaurus dorsalis dorsalis.	*Uta graciosa.*	*Cnemidophorus martyris.*
Crotaphytus collaris baileyi.	*Uta parva.*	*Pituophis catenifer deserticola.*
Sauromalus hispidus.	*Phrynosoma platyrhinos.*	
Callisaurus splendidus.	*Phrynosoma solare.*	

Birds of Lower Sonoran Zone.—Among the birds the desert thrashers (*Toxostoma*), cactus wrens, verdins, white-throated towhees, Xantus jays, ash-throated flycatchers, road runners, gilded flickers, ladder-backed and Gila woodpeckers, and white-winged doves are the most common and generally distributed. In addition the ravens, Harris hawks, and Mexican falcons are not uncommon.

Characteristic birds of the Lower Sonoran zone listed according to the faunal districts in which they occur.

Northeastern section (Colorado Desert district).	Middle section (Vizcaino Desert district).	Southern section (cape district).
Butorides virescens anthonyi.		
Ardea herodias treganzai.		
Lophortyx gambelii gambelii.	*Lophortyx californica vallicola.*	*Lophortyx californica vallicola.*
Melopelia asiatica mearnsi.	*Melopelia asiatica mearnsi.*	*Melopelia asiatica mearnsi.*
Parabuteo unicinctus harrisi.	*Parabuteo unicinctus harrisi.*	*Parabuteo unicinctus harrisi.*
		Cerchneis sparveria peninsularis.
		Otus asio xantusi.
Bubo virginianus pallescens.	*Bubo virginianus elachistus.*	*Bubo virginianus elachistus.*
Dryobates scalaris cactophilus.	*Dryobates scalaris eremicus.*	*Dryobates scalaris lucasanus.*
Centurus uropygialis uropygialis.	*Centurus uropygialis brewsteri.*	*Centurus uropygialis brewsteri.*
Colaptes chrysoides mearnsi.	*Colaptes chrysoides brunnescens.*	*Colaptes chrysoides chrysoides.*
Myiarchus cinerascens cinerascens.	*Myiarchus cinerascens pertinax.*	*Myiarchus cinerascens pertinax.*
Otocoris alpestris leucansiptila.	*Otocoris alpestris enertera.*	*Otocoris alpestris enertera.*
Molothrus ater obscurus.		
	Aphelocoma californica hypoleuca.	*Aphelocoma californica hypoleuca*
Agelaius phoeniceus sonoriensis.		
	Amphispiza nevadensis cinerea.	
Carpodacus mexicanus frontalis.		*Carpodacus mexicanus ruberrimus.*
Melospiza melodia saltonis.		
	Pipilo fuscus aripolius.	*Pipilo fuscus albigulus.*
Dendroica aestiva sonorana.		
Geothlypis trichas occidentalis.		
Toxostoma bendirei.	*Toxostoma cinerea mearnsi.*	*Toxostoma cinerea cinerea.*
Toxostoma lecontei lecontei.	*Toxostoma lecontei arenicola.*	
Heleodytes brunneicapillus couesi.	*Heleodytes brunneicapillus affinis.*	*Heleodytes brunneicapillus affinis.*
Auriparus flaviceps flaviceps.	*Auriparus flaviceps lamprocephalus.*	*Auriparus flaviceps lamprocephalus.*
Polioptila plumbea plumbea.	*Polioptila plumbea plumbea.*	*Polioptila plumbea plumbea.*

Mammals of Lower Sonoran Zone.—The usual mammal genera of the southwestern deserts are here in abundance, including *Antilocapra*, *Ammospermophilus*, *Peromyscus*, *Neotoma*, *Dipodomys*, *Perognathus*, *Lepus*, *Sylvilagus*, *Canis*, and *Vulpes*. On the desert ranges of the eastern part of the peninsula mountain sheep are numerous. The characteristic mammals of the Lower Sonoran zone are listed according to the faunal districts, as follows:

Characteristic mammals of the Lower Sonoran zone listed according to the faunal districts in which they occur.

Northeastern section (Colorado Desert district).	Middle section (Vizcaino Desert district).	Southern section (cape district).
Odocoileus hemionus eremicus.	*Odocoileus hemionus eremicus.*	*Odocoileus hemionus peninsulae.*
Antilocapra americana peninsularis.	*Antilocapra americanus peninsularis.*	*Antilocapra americanus peninsularis.*
Ovis canadensis cremnobates.	*Ovis canadensis cremnobates.*	*Ovis canadensis cremnobates.*
Citellus tereticaudus.		*Citellus atricapillus.*
	Eutamias merriami meridionalis.	
Ammospermophilus leucurus leucurus.	*Ammospermophilus leucurus peninsulae.*	*Ammospermophilus leucurus peninsulae.*
Castor canadensis frondator.		*Ammospermophilus leucurus insularis* (Espiritu Santo Island).
Onychomys torridus perpallidus.		
Peromyscus maniculatus sonoriensis.	*Peromyscus maniculatus coolidgei.*	*Peromyscus maniculatus magdalenae* (Magdalena Island).
Peromyscus crinitus stephensi.		*Peromyscus maniculatus margaritae* (Margarita Island).
Peromyscus eremicus eremicus.	*Peromyscus eremicus eva*	*Peromyscus eremicus eva.*
Sigmodon hispidus eremicus.		*Peromyscus eremicus avius* (Ceralvo Island).
Reithrodontomys megalotis megalotis.		*Peromyscus eremicus insulicola* (Espiritu Santo Island).
		Peromscus eremicus polypolius (Margarita Island).
Neotoma albigula venusta.		*Neotoma intermedia pretiosa.*
Neotoma intermedia gilva.		*Neotoma intermedia arenacea.*
Neotoma lepida.		*Neotoma intermedia vicina.*
Fiber zibethicus pallidus.		*Neotoma intermedia perpallida* (San Jose Island).
		Neotoma abbreviata (San Francisco Island).
		Neotoma nudicauda (Carmen Island).
	Thomomys bottae russeolus.	*Thomomys bottae anitae.*
		Thomomys magdalenae (Magdalena Island).
Dipodomys deserti.	*Dipodomys platycephalus.*	*Dipodomys merriami melanurus.*
Dipodomys merriami simiolus.		*Dipodomys margaritae* (Margarita Island).
		Dipodomys insularis (San Jose Island.)
	Perodipus simulans peninsularis.	
	Perognathus baileyi rudinoris.	*Perognathus baileyi rudinoris.*
Perognathus penicillatus angustirostris.	*Perognathus penicillatus arenarius.*	*Perognathus penicillatus arenarius.*
		Perognathus penicillatus ammophilus (Margarita Island).
		Perognathus penicillatus siccus (Ceralvo Island).
Perognathus fallax pallidus.		
Perognathus spinatus spinatus.	*Perognathus spinatus spinatus.*	*Perognathus spinatus peninsulae.*
		Perognathus spinatus magdalenae (Magdalena Island).
		Perognathus spinatus margaritae (Margarita Island.).
		Perognathus spinatus bryanti (San Jose Island).
Lepus californicus deserticola.	*Lepus californicus martirensis.*	*Lepus californicus xanti.*
		Lepus californicus magdalenae (Magdalena Island).
		Lepus insularis (Espiritu Santo Island).
Sylvilagus arizonae arizonae.	*Sylvilagus auduboni confinis.*	*Sylvilagus auduboni confinis.*
	Sylvilagus bachmani exiguus.	*Sylvilagus bachmani peninsularis.*
		Sylvilagus mansuetus (San Jose Island).
Felis aztecus browni.	*Felis aztecus.*	*Felis aztecus.*
Lynx ruffus baileyi.	*Lynx ruffus californicus.*	*Lynx ruffus californicus.*
Canis mearnsi.	*Canis peninsulae.*	*Canis peninsulae.*
Canis lestes.		

Characteristic mammals of the Lower Sonoran zone listed according to the faunal districts in which they occur—Continued.

Northeastern section (Colorado Desert district).	Middle section (Vizcaino Desert district).	Southern section (cape district).
Urocyon cinereoargenteus scotti.	*Urocyon cinereoargenteus californicus.*	
Vulpes macrotis macrotis.	*Vulpes macrotis devia.*	*Vulpes macrotis devia.*
		Bassariscus astutus palmarius.
		Bassariscus astutus insulicola (San Jose Island).
		Bassariscus astutus saxicola (Espiritu Santo Island).
Procyon psora pallidus.		*Procyon psora.*
Taxidea taxus infusca.	*Taxidea taxus infusca.*	*Taxidea taxus infusca.*
		Spilogale microdon.
		Spilogale lucasana.
		Mormoops megalophylla senicula.
	Chaeronycteris mexicana.	*Chaeronycteris mexicana.*
Mephitis mesomelas estor.		
Myotis yumanensis.	*Natalus mexicanus.*	*Myotis volans.*
		Myotis peninsularis.
		Myotis micronyx.
		Pipistrellus hesperus australis.
		Eptesicus fuscus peninsulae.
Antrozous pallidus pallidus.	*Antrozous pallidus minor.*	*Antrozous pallidus minor.*
		Nyctinomus depressus.

Upper Sonoran Zone.

The Upper Sonoran zone in Lower California is broken into numerous areas of varying size distributed from the northern border south nearly to Cape San Lucas. The largest area is that described as the San Diegan district in the account of the subordinate faunal areas (p. 118). This is the southern extension of the coastal belt from southern California. It occupies the northwestern part of Lower California from the Pacific coast up to an altitude of about 4,000 to 4,500 feet on the west slope of the Juarez Mountains and to 6,000 to 6,500 feet on the same slope of the San Pedro Martir Mountains. It extends from the northern boundary south to near El Rosario, narrowing rapidly south of San Quintin. The Upper Sonoran zone limits are still undetermined on the east slope of the Juarez-San Pedro Martir Range, but the lower border must be between 4,000 and 4,500 feet. The higher mountain tops rising above an altitude of about 4,500 feet from the southern end of the San Pedro Martir Mountains to the southern end of the peninsula are Upper Sonoran.

The Coronados, Todos Santos, San Martin, San Geronimo, the San Benitos, and Natividad Islands belong to this zone. It also covers the northern and western slopes of Cedros Island except the upper part of the high northwest slope, which is probably Transition; the arid eastern and southern slopes are Lower Sonoran. Guadalupe Island, still farther offshore, surrounded by cold ocean currents, appears to be Upper Sonoran on its lower slopes, Transition in the middle parts, and approaching Canadian on the northerly slopes of its cold foggy summit. No detailed work has been done, however, to outline the zones on Guadalupe, so they can be stated only in a a general way.

From the San Pedro Martir Mountains to La Paz Bay the higher elevations occur only as small solitary peaks, so the areas of Upper Sonoran are extremely limited, resulting merely in a series of scattered and widely spaced barren islets of this zone with but slight traces of the flora and fauna proper to the climatic conditions. One of the best marked of these Upper Sonoran islands is on the summit of the high mountain south of the old mission of Calamahue, where we saw a thin growth of small oaks or pinyon pines, but were not near enough to identify them further. Immediately north of La Paz Bay Mechudo Peak forms one of these islets. South of La Paz Bay the tops of the Sierra Laguna and other parts of the Sierra Victoria, above about 4,500 feet, is well-marked Upper Sonoran. This area is 30 miles or more in extent and is covered by a growth of scrubby oaks, with pinyon pines (*Pinus cembroides*) on the high parts of the Sierra Laguna.

Close along the seashore in the San Diegan district the slopes exposed to the salt air are practically without shrubby growth, the surface being overgrown with grasses and other her-

baceous plants. Farther back on the mountain slopes and borders of the interior valleys there is commonly an abundant shrubby growth, often forming dense chaparral, especially in canyons like that on the mountain slopes in San Diego County, Calif.

Along the slopes of the Juarez-San Pedro Martir Mountains there is a definite belt of pinyon pines all within the Upper Sonoran life zone. Botanists have identified three species among these pinyons, but their relative distribution is little known. The Parry pinyon (*Pinus quadrifolia*) is the most abundant and widely distributed of the species. It grows on both slopes of the mountains and in places spreads over broad areas, especially along the northwestern slopes of the San Pedro Martir Mountains and thence over outlying foothills; also on the southwestern slopes of the Sierra Juarez and the outlying hills of the Alamo Plain. On the west slope of all these mountains the pinyons extend from about 4,000 feet up into the border of the Jeffrey yellow pines at from 4,800 to 6,000 feet. Their lower limit is rather lower on the west slopes than on the arid eastern side of the range. On hot sheltered south slopes at 9,000 feet near the head of Canyon Diablo, in the San Pedro Martir Mountains, we saw small stunted pinyons, but their ordinary limits are far below this. They extend north within a few miles of the California border and south along the Rosario divide to the tops of the mesas about Matomi Canyon, the extreme southern limit of the pines in this section.

The birds and mammals of the San Diegan district in Lower California are the same or are closely related to those inhabiting the coastal belt of the San Diego district north of the border. In the Upper Sonoran part of the cape district the birds are nearly all different, mainly subspecifically, from those in the San Diegan part of this zone and number among them the most striking and characteristic members of the bird fauna of what has been known as the "Cape Region." The mammals also differ but are much less numerous.

The subjoined lists of mammals, plants, reptiles and birds of the two main Upper Sonoran areas of the peninsula show the characteristics of each. Additional notes on each of these Upper Sonoran areas are given in the descriptions of the subordinate faunal areas on pages 117–121.

PLANTS CHARACTERIZING THE UPPER SONORAN ZONE IN NORTHWESTERN LOWER CALIFORNIA (SAN DIEGAN DISTRICT).

[Species marked with an asterisk (*) occur also in California.]

**Juniperus californica.*
**Pinus quadrifolia.*
**Pinus monophylla.*
**Pinus monophylla edulis.*
Ephedra californica.
**Hesperoyucca whipplei.*
Nolina palmeri.
**Quercus agrifolia.*
**Quercus dumosa.*
**Quercus tomentella.*
Quercus palmeri.
**Eriogonum fasciculatum.*
Eriogonum polifolium.
**Berberis fremontii.*
Grossularia quercetorum.
**Ribes indecorum.*
**Platanus racemosa.*
**Adenostoma fasciculatum.*
**Adenostoma sparsifolium.*
**Cercocarpus parvifolius.*
**Heteromeles arbutifolia.*
Rosa minutifolia.
**Emplectocladus fasciculatus.*
**Prunus ilicifolia.*
**Cneoridium dumosum.*
Schmaltzia ribifolia.
Aesculus parryi.
**Adolphia infesta.*
Ceanothus goldmani.
Ceanothus submontanus.
Ceanothus palmeri.
**Rhamnus crocea.*
**Fremontodendron californicum.*
Bergerocactus emoryi.
**Garrya veatchii palmeri.*
Arctostaphylos bicolor.
**Arctostaphylos glauca.*
Arctostaphylos oppositifolia.
**Fraxinus attenuata.*
**Eriodictyon angustifolium.*
**Eriodictyon sessilifolium.*
**Ramona polystachya.*
Diplacus arachnoideus.
Diplacus puniceus.
Pentstemon centranthifolius.
**Pentstemon antirrhinoides.*
**Lonicera interrupta.*
**Sambucus glauca.*
**Artemisia californica.*
**Artemisia tridentata.*
**Coleosanthus atractyloides.*

PLANTS CHARACTERIZING THE UPPER SONORAN ZONE IN SOUTHERN LOWER CALIFORNIA (CAPE DISTRICT).

[Species marked with an asterisk (*) occur also on the Mexican mainland.]

**Pinus cembroides.*
Nolina beldingi.
Populus monticola
**Salix lasiolepis.*
Quercus devia.
Thalictrum peninsulare.
Ribes brandegei.
Heteromeles arbutifolia.
Rubus sp.
Garrya salicifolia.
Arbutus peninsularis.
Salvia similis.
Tagetes lacera.

Reptiles of Upper Sonoran Zone, San Diegan District.—The following reptiles are characteristic of the San Diegan district of Upper and Lower California. Too little is known of

the distribution of the reptiles of this zone in the cape district to warrant trying to separate the zonal elements there. The reptiles of the cape district as a whole are enumerated in the general discussion of the reptiles (p. 115).

Uta stansburiana hesperis.
Sceloporus occidentalis bi-seriatus.
Sceloporus orcutti.
Phrynosoma cerroense.
Cnemidophorus labialis.
Lichanura roseofusca.
Pituophis catenifer annectens.
Thamnophis ordinoides hammondii.

Birds of Upper Sonoran Zone—The Upper Sonoranzone of the peninsula is isolated in two main sections, the first or most northern in the extreme northwest adjoining California, and the second confined to the mountain slopes near the southern end mainly south of La Paz. For purposes of comparison the birds of the two areas are listed separately.

BIRDS CHARACTERISTIC OF THE UPPER SONORAN ZONE.

NORTHWESTERN SECTION (SAN DIEGAN DISTRICT).

Rallus levipes.
Gymnogyps californianus.
Balanosphyra formicivora bairdi.
Dryobates nuttallii.
Phalaenoptilus nuttallii californicus.
Archilochus alexandri.
Tyrannus verticalis.
Otocoris alpestris actia.
Aphelocoma californica obscura.
Cyanocephalus cyanocephalus.
Sturnella neglecta neglecta.
Agelaius phoeniceus neutralis.
Carpodacus mexicanus clementis.
Astragalinus lawrencei.
Astragalinus psaltria hesperophilus.
Passerculus beldingi.
Passerculus rostratus halophilus.
Amphispiza belli.
Aimophila ruficeps ruficeps.
Melospiza melodia cooperi.
Pipilo fuscus senicula.
Passerina amoena.
Lanius ludovicianus gambeli.
Vireo bellii pusillus.
Vireo vicinior.
Toxostoma rediviva helva.
Toxostoma crissale.
Thryomanes bewickii charienturus.
Baeolophus inornatus murinus.
Psaltriparus minimus minimus.
Chamaea fasciata henshawi.
Polioptila californica.

SOUTHERN SECTION (CAPE DISTRICT SOUTH OF LA PAZ).

Chloroenas fasciata vioscae.
Glaucidium gnoma hoskinsii.
Otus asio xantusi.
Balanosphyra formicivora angustifrons.
Phalaenoptilus nuttallii nuttallii.
Basilinna xantusi.
Junco bairdi.
Aimophila ruficeps sororia.
Pipilo maculatus magnirostris.
Tachycineta thalassina brachyptera.
Lanivireo solitarius lucasanus.
Vireo huttoni cognatus.
Sitta carolinensis lagunae.
Baeolophus inornatus cineraceus.
Psaltriparus minimus grindae.
Planesticus confinis.

MAMMALS CHARACTERISTIC OF THE UPPER SONORAN ZONE.

NORTHWESTERN SECTION (SAN DIEGAN DISTRICT).

Odocoileus cerrosensis (Cedros Island).
Citellus beecheyi beecheyi.
Citellus beecheyi fisheri.
Onychomys torridus ramona.
Peromyscus maniculatus gambeli.
Peromyscus maniculatus dubius (Todos Santos Island).
Peromyscus maniculatus geronimensis (San Geronimo Island).
Peromyscus maniculatus cineritius (San Roque Island).
Peromyscus californicus insignis.
Peromyscus eremicus fraterculus.
Peromyscus eremicus cedrosensis (Cedros Island).
Reithrodontomys megalotis longicaudus.
Reithrodontomys megalotis peninsulae.
Neotoma intermedia intermedia.
Neotoma fuscipes macrotis.
Neotoma bryanti (Cedros Island).
Neotoma anthonyi (Todos Santos Island).
Neotoma martinensis (San Martin Island).
Microtus californicus huperuthrus.
Thomomys bottae nigricans.
Dipodomys merriami parvus.
Perodipus simulans.
Perognathus pacificus.
Perognathus penicillatus helleri.
Perognathus fallax fallax.
Perognathus anthonyi (Cedros Island).
Perognathus femoralis femoralis.
Perognathus femoralis mesopolius.
Lepus californicus bennetti.
Sylvilagus auduboni sanctidiegi.
Sylvilagus bachmani cinerascens.
Sylvilagus bachmani cerrosensis (Cedros Island).
Urocyon cinereoargenteus californicus.
Procyon psora.
Taxidea taxus californica.
Mephitis occidentalis holzneri.
Sorex californicus juncensis.

SOUTHERN SECTION (CAPE DISTRICT).

Ovis canadensis cremnobates.	*Thomomys bottae alticola.*
Peromyscus truei lagunae.	*Sorex lagunae.*

Transition Zone (San Pedro Martir District).

In Lower California this zone is confined to an isolated belt, nowhere exceeding 12 or 15 miles in width and perhaps 150 miles in length, along the upper slopes of the Juarez-San Pedro Martir Mountains. It is limited on the north at a point within 15 or 20 miles of the California boundary, where the general elevation of the Sierra Juarez is depressed and the Upper Sonoran zone comes in. This lower belt extends to about an equal distance north of the boundary, so the gap between the nearest definite Transition zone areas on the two sides of the border appears to be at least 30 to 40 miles. The lower limit of the zone on the west side of the Sierra Juarez is about 4,800 feet and a little higher on the east slope. On the west slope of the San Pedro Martir Mountains the lower limit is from 6,000 to 6,500 feet and about 6,500 to 7,000 feet on the east slope. It extends thence up to the top of the main ridges at over 9,000 feet. Above this the only elevations are the bare ragged granite crests leading to the top of La Providencia Peak, which are too limited in size and barren of vegetation to show zonal characteristics.

This Transition zone area is characterized by a scattered forest of yellow pines (*Pinus ponderosa jeffreyi*) with a thin mixture of sugar pines (*Pinus lambertiana*), the incense cedar (*Libocedrus*), and other species of plants also characteristic of this zone in the mountains of southern California, including a mixture of *Pinus coulteri* among the Jeffrey yellow pines on the Sierra Juarez. (See Pl. 26, Fig. 1.) The animal life here is also very similar to that of the more northern mountains, but a few local subspecies have developed in this isolated tract, as shown by the subjoined lists.

Sceloporus graciosus vandenburghianus is the only reptile I can locate as belonging to this zonal area, although *Gerrhonotus scincicauda webbii* is also found there and in adjacent parts of the Upper Sonoran zone.

Intermingled with the Transition zone species on the top of the San Pedro Martir Mountains are a few species of birds and plants belonging to the Canadian zone. Owing to the fact that these species form only a subordinate element in the upper part of the Transition area it is evident that they represent merely the usual overlapping along the border and no part of these mountains can be mapped as belonging to the Canadian zone. The possible exception to this statement is that of the bare granite crest of Santa Catalina Peak, rising over 10,000 feet above sea level, but its area is insignificant and it appears almost wholly devoid of vegetation. The representatives of the Canadian zone noted on these mountains are listed beyond.

PLANTS CHARACTERIZING THE TRANSITION ZONE (SAN PEDRO MARTIR DISTRICT).

[Species marked with an esterisk (*) occur also in California.]

Cupressus guadalupensis (?).	**Quercus chrysolepis.*	*Arctostaphylos pringlei.*
**Libocedrus decurrens.*	**Philadelphus pumilus.*	**Ramona incana pachystachya.*
**Pinus ponderosa jeffreyi.*	**Holodiscus dumosus.*	**Monardella linoides.*
**Pinus coulteri.*	**Rosa californica.*	**Monardella macrantha.*
**Pinus lambertiana.*	**Ceanothus divaricatus.*	*Pentstemon linarioides.*
**Populus trichocarpa.*	**Rhamnus californica.*	

BIRDS CHARACTERISTIC OF THE TRANSITION ZONE (SAN PEDRO MARTIR DISTRICT).

Oreortyx picta confinis.	*Pipilo maculatus megalonyx.*	*Troglodytes aedon parkmanii.*
Colaptes cafer collaris.	*Piranga ludoviciana.*	*Sitta carolinensis aculeata.*
Empidonax difficilis cineritius.	*Progne subis hesperia.*	*Sitta pygmaea leuconucha.*
Cyanocitta stelleri frontalis.	*Tachycineta thalassina lepida.*	*Penthestes gambeli baileyae.*
Euphagus cyanocephalus.	*Lanivireo solitarius cassinii.*	*Sialia mexicana anabelae.*
Junco oreganus townsendi.	*Cinclus mexicanus unicolor.*	

MAMMALS CHARACTERISTIC OF THE TRANSITION ZONE (SAN PEDRO MARTIR DISTRICT).

Odocoileus hemionus californicus.	*Peromyscus boylei rowleyi.*	*Sorex ornatus.*
Sciurus douglasii mearnsi.	*Neotoma intermedia intermedia.*	*Scapanus latimanus anthonyi.*
Eutamias merriami obscurus.	*Neotoma fuscipes macrotis.*	*Myotis orinomus.*
Citellus beecheyi fisheri.	*Canis clepticus.*	*Myotis evotis milleri.*
Peromyscus truei martirensis.	*Spilogale arizonae martirensis.*	*Eptesicus fuscus fuscus.*
Peromyscus maniculatus sonoriensis.		

Canadian Zone.

As already noted a small infusion of Canadian zone species of plants and animals occurs in the higher and colder parts of the Transition zone on the San Pedro Martir Mountains.

The only mammal of Canadian zone affiliations is *Sciurus douglasi mearnsi*, which here, in common with the birds named below, ranges well through the Transition zone.

The birds belonging in this zone are:

Nucifraga columbiana (rare).	*Spinus pinus.*	*Carpodacus cassini.*

The most notable plants belonging here are:

Abies concolor.	*Populus tremuloides.*	*Symphoricarpos parishii.*
Pinus contorta.		

All of these are well-known species in the mountains of California.

NATURAL RESOURCES IN ANIMAL AND PLANT LIFE.

Land Game Mammals.

Early in its history Lower California abounded in game. Mule deer were abundant throughout the peninsula and on some of the adjacent islands. Antelope roamed over the desert plains from the border of California to beyond Magdalena Bay. Mountain sheep occupied the barren desert ranges mainly in the middle and eastern parts of the peninsula from the northern border south to the northern side of La Paz Bay.

Coyotes, mountain lions, and bobcats were numerous and are still common in places. I have been unable, however, to find any definite record of wolves ever having occurred in the peninsula, and conditions there do not appear to be favorable for them. The only record of bears is that of the grizzly, mentioned as occurring in the Sierra Juarez by Pattie.

It is of interest to note that the first mountain sheep reported from America by Europeans were those described by the Spanish missionaries in Lower California early in the occupation of the region. These sheep, although the first to become known to Europeans, were among the latest on this continent to receive a scientific designation, having been described in 1903 from specimens obtained at Matomi as *Ovis cervina cremnobates*. The mountain sheep of Lower California average smaller than those of the northern Rocky Mountain region. They wander from sea level on the shores of the gulf to an altitude of less than 5,000 feet on the slopes of the mountains, and occur mainly at elevations between 1,000 and 3,000 feet. They are strictly limited to elevations below the lower limit of pine forests. Although far less numerous than formerly and steadily diminishing in numbers, mountain sheep still occur in many of the mountain ranges from near the California border south almost to La Paz Bay.

Unfortunately, the difficulties of transportation and the scarcity of live stock through most parts of the peninsula render the securing of food supplies so difficult that great numbers of game animals, especially mountain sheep, have been killed and the meat dried, or jerked, to supply mining camps and other communities. This deplorable and wasteful slaughter still continues and unless checked will ultimately result in the extermination of the sheep and all other large game animals of that region. Mountain sheep are peculiarly endangered by this slaughter owing to their habit of going in bands and drinking at certain watering places, where hunters lie in wait behind blinds built of loose stones and kill individuals of all ages and sexes, often in a few minutes destroying an entire band. I have been informed of one party having killed more than 100 sheep in this manner to make dried meat during a single season.

On the mainland of the peninsula occur two, and perhaps three, forms of the mule deer, none of them strikingly different from the typical animal of the Rocky Mountains, except that in the south the horns appear to average smaller. The mule deer of Cedros Island differs strikingly from the typical animal in its dwarfed antlers. Those on San Jose Island, in the gulf, so far as known, are the same as those on the adjacent mainland of the peninsula. About 20 years ago mule deer were abundant about the delta of the Colorado, occurring there during the winter season in bands. At present they are almost exterminated in this area. Elsewhere in the peninsula, although in many places reduced below their former numbers, they are still more or less generally distributed from sea level up to 9,000 feet on the higher parts of the San Pedro Martir Mountains, and to 6,000 feet on the Sierra Victoria in the south. They are still numerous on the upper slopes of both these ranges and on parts of the Magdalena Plain.

Antelopes, once so numerous on the open plains of the peninsula, have become exterminated over considerable areas. None appear to be left in the northwestern part of the peninsula west of the mountains, and north of El Rosario. They are also gone from the great Magdalena Plain. Small numbers still exist on the desert south of the Cocopah Mountains and back of San Felipe Bay, as well as in various other localities, thence south to the Vizcaino Desert, where they are still more numerous than elsewhere. It is evident, however, that these animals are fated to disappear from this region in the not distant future.

In addition to the larger game of the peninsula, jack rabbits and cottontails are common practically throughout its extent, varying in abundance according to the seasons, whether these are favorable or unfavorable for the production of abundant food. The jack rabbits and cottontails of the entire peninsula and the brush rabbits found in the northwestern portion are all geographic races of the species occurring in California.

So far as known, the only game law ever issued for the protection of land game in Lower California is one promulgated for the protection of mountain sheep, of which the translation is given below. Unfortunately, no effective enforcement of this regulation appears to have been undertaken.

UNITED STATES OF MEXICO.

GOVERNMENT OF THE NORTHERN DISTRICT OF LOWER CALIFORNIA.

Notice.

By order of the superior authority and until futher notice the hunting or exploitation of mountain sheep (*Ovis cremnobates*) in this district is strictly prohibited.

This is for the information of the authorities of the district and the public in general for its observance, with the understanding that infractions of this order will be punished according to law.

Mexicali, Baja California, October 10, 1917.

E. CANTÚ,
Governor of the District.

J. BARRERA,
Secretary of the Government.

Sea Game Mammals.

From the time of its discovery until the early part of the last century the coasts of Lower California were frequented by enormous numbers of whales, which resorted to the numerous bays and inlets to breed. Among the more notable of these were the sperm and California gray whales. Fur seals, elephant seals, sea otters, sea lions, and spotted, or harbor, seals also abounded.

During the first half of the last century whalers, sealers, and sea otter hunters united in such uncontrolled slaughter of these valuable animals that their numbers rapidly decreased to a point where their pursuit came to an end for lack of an object. The seals, sea otter, and sea elephants have disappeared forever as an economic factor. There is no record of a single individual of fur seal or sea otter having been obtained for many years within the waters of the peninsula, and sea elephants have disappeared except for a small number which were discovered in 1911 haunting the westward shores of Guadalupe Island. The sea otter, sea ele-

phant, and fur seal ranged mainly along the northwestern coast of the peninsula from the vicinity of Ensenada to Cedros Island. Sea lions, and to a lesser extent harbor seals, have been killed on a smaller scale along both shores of the peninsula during the past and up to the present time. In the Gulf of California they are hunted in small fishing boats, and on the islands of San Pedro Martir, Angel de la Guarda, and San Lorenzo. It is recorded that in 1884 hunters from Mulege killed 287 sea lions. The hunting of these animals for their skins and oil is unorganized and sporadic. Their numbers are too small to warrant systematic exploitation.

Game Birds.

Land game birds are poorly represented in the peninsula. No species of grouse occurs. There are, however, Gambel's quail in the northeastern section and California quail in the northwest, and thence south throughout most of the peninsula wherever permanent water occurs. The mountain quail is plentiful in the wooded and brushy parts of the higher elevations of the Juarez and San Pedro Martir Mountains (up to above 8,500 feet on the latter range). In addition, a local form of the band-tailed pigeon is numerous in the limited wooded area of the Victoria Mountains in the southern end of the peninsula. Mourning doves are common everywhere in the vicinity of permanent water.

Many species of ducks and several species of geese winter in great numbers in the delta of the Colorado, and in the San Quintin Bay and Scammon Lagoon. These two bays are the main winter homes of the black brant. Ducks are rather common wherever sufficient permanent fresh water exists in the southern part of the peninsula, but never in any very great numbers.

Fisheries.

The waters about both coasts of Lower California abound in food and game fishes to such an extent that eventually they must become enormously valuable as a source of supply to the adjacent regions. Dr. C. H. Townsend, who conducted fishery investigations in the Gulf of California during the expedition of the Fish Commission steamer *Albatross* in 1911, states that during his work he found numerous excellent food fishes readily obtainable with hand lines and seines at most of the anchorages. He found that several food fishes of the Atlantic coast occur in the Gulf of California, among which may be mentioned the Spanish mackerel, chub, mackerel, mullet, jack, crevally, and jewfish. In addition were many native fishes of importance. One of these, known locally as the sea bass, is the largest of the weak fishes, reaching a weight of 175 pounds, and is a valuable food fish. It is abundant at the head of the gulf and enters the mouth of the Colorado, where it is taken by spearing. Another weak fish called "blue fish" in southern California is abundant. The excellent "pez de gallo" is abundant in the upper parts of the gulf and reaches a length of 4 feet. Among the more or less common species are the barracuda and yellow-tailed grouper, which are of large size and are plentiful at the mouth of the Colorado, running up the river as far as there is brackish water. Dr. Townsend says that a few California yachtsmen have found their way into the upper parts of the gulf and have enjoyed the best of sport with rod and reel.

A species of trout (*Salmo nelsoni*) related to the rainbow trout of California was discovered by us in a single stream, the Arroyo San Antonio, on the west slope of the San Pedro Martir Mountains. This stream forms the main headwater tributary on the Rio Santo Domingo. These trout are all below the waterfall in the Arroyo San Antonio and probably occupy less than 15 miles of its length. They do not attain a large size and are in such limited numbers that it would not be difficult to destroy them by overfishing. Their numbers are sometimes much reduced by floods down the canyon which fill the stream bed with moving rocks, sand, and gravel.

Along the northwestern shore of the peninsula, especially in the vicinity of San Quintin Bay, occur great numbers of the large crayfish, which replaces the lobster on the Pacific coast. A cannery was once established near the mouth of San Quintin Bay to pack these crustaceans. Although the crayfish were found in sufficient abundance, yet certain local difficulties resulted in the abandonment of the enterprise and the establishment was idle in 1905. During the

season of 1918 and 1919 a cannery for packing sardines and tuna has been in operation at San Quintin. In addition, several fishing companies of San Pedro and San Diego, Calif., have been operating fishing boats along the northwest coasts of the peninsula, taking tuna, mackerel, crayfish, abalone, and other sea products for the California market.

Green sea turtles are plentiful about the southern coast, especially from Cape San Eugenio south to beyond Santa Margarita Island and also along most of the gulf shore. Many turtles have been taken in the vicinity of Magdalena Bay and shipped to San Francisco on Pacific mail steamers. At one time a small canning factory was established on the east shore of Santa Margarita Island for the purpose of putting up turtle meat, but it is reported that through the inexperience of those in charge the experiment proved a failure.

Pearl Oysters.

Within a short time after the occupation of the peninsula by the Spaniards it was discovered that pearl oysters were plentiful along the southern half of the gulf shore of the peninsula, and from that time until the present with short intervals an annual harvest of pearls and pearl shell has been obtained. Owing to overfishing the pearl oyster beds in many places were destroyed and the yield throughout has decreased. Early in 1906, when we were at La Paz, we found a local company was experimenting in farming pearl oysters on Espiritu Island, at the mouth of La Paz Bay. It has since been learned that this experiment has been successful, indicating that Lower California thus presents an opportunity for an attractive new industry. The pearl oysters are reported to do best in from 1 to 10 fathoms of water.

In addition to pearl oysters Dr. Townsend reports that edible oysters "not distinguishable from those of our Atlantic States are abundant at several points in the Gulf of California as far north as Georges Bay."

Pine Forests.

In all of Lower California only two limited areas contain merchantable timber. Both of these are in the north. The first, which is about 3 miles in width by 37 miles in length, lies along the crest of the northern part of the Sierra Juarez, in the section known locally as the Sierra del Pinal, or Laguna Hanson Mountains; the second, about 6 miles in width by 45 miles in length, occupies the crest of the Sierra San Pedro Martir. These areas include all of the yellow pine, sugar pine, lodge-pole pine, incense cedar, and fir trees of the peninsula in a total area of less than 400 square miles.

The greater part of the pine timber in the Juarez Mountains is readily accessible by existing wagon roads, and several small mills have already cut much of the best growth for local use.

On the San Pedro Martir Mountains the timbered area is isolated on the elevated summit and only accessible by trail leading up over several thousand feet of abrupt and rugged mountain slopes. The top of the mountains where it occurs is much broken and forms numerous small pocketlike valleys and mesas separated by altitudes varying from one to two thousand feet and by canyons and excessively rocky slopes. The pine forest grows over the ridges and in many small isolated areas or as narrow belts about the borders of valleys and along the bases of rocky ridges, as shown in accompanying photographs. As a result of its isolation on the top of the San Pedro Martir Mountains and the scattered distribution of the timber due to the broken and rocky character of the mountain summit, the cost of utilizing the timber on these mountains would be exceedingly high and would not be practicable at present. In both of the areas mentioned the timber in places is fairly large, but the majority of it is scrubby. The forest is commonly mixed in character but the yellow pines and the lodge-pole pines each occur in many places in practically unmixed growths. The sugar pines, the incense cedars, and the firs do not occur in any considerable numbers.

Orchilla.

A lichen belonging to the genus *Roccella*, commonly known as the orchilla, grows in abundance on the desert shrubs and other plants occurring in a narrow belt along the Pacific coast from the shores of Magdalena Bay north to a short distance beyond Vizcaino Desert. (See Pl. 30, Fig. 1.) This lichen hangs in long gray strands very similar in appearance to the Spanish moss

so plentiful in the Gulf States. It was formerly the basis of a considerable industry centered at Magdalena Bay, being gathered in great quantities, baled, and shipped to England and Germany for dyeing purposes. Large warehouses were erected at Magdalena Bay and the Chartered Co. of Lower California became a wealthy corporation in exploiting this product. With the discovery of aniline dyes, and their cheap production, the orchilla industry was abandoned, and commercial activity at Magdalena Bay ceased.

Tanbark.

One of the most important trees of the peninsula from an economic point of view is the palo blanco (*Lysiloma candida*), a tropical species which occurs abundantly in many places in the cape region from Santa Ana Canyon, in the lava plateau north of San Ignacio south to Cape San Lucas. (See Pl. 33.) The gathering and exportation of its bark for tanning purposes is one of the leading industries of the district where it occurs. The main shipping point for this product is San Jose del Cabo.

Dye Bark.

The bark of the torote (*Bursera microphylla*) is still gathered and shipped from the cape district for dyeing purposes.

Kelp.

Kelp beds similar to those off the coast of southern California occur along the west coast of Lower California from near the northern border south to the vicinity of Cedros Island. In 1918, following the development of the kelp industry on the coast of California, more than $100,000 was invested under Gov. Cantú's direction in the development of a plant at Sausal, 6 miles northwest of Ensenada, for treating kelp to produce potash and other products. The plant established by Gov. Cantú, including boats, kelp-harvesting machinery, and other apparatus, was in readiness for gathering and treating between 200 and 300 tons of kelp a day when the armistice which brought the Great War to a close ended the exigency need of potash and caused the abandonment of this enterprise.

Wild Fruits.

The wild fruits of Lower California were of much importance to the original inhabitants but have little to recommend them now. They include mainly the fruits of several species of cactus, including the pitahaya agria and pitahaya dulce (*Lamaireocereus thurberi* and *L. gummosus*); also the ciruela (*Tapirira edulis*) of the south, a small yellow plum of peculiar taste which is a relative of the pistachio nut. Pinyon nuts are still gathered as food by some of the few surviving Indians, especially along the western base of the San Pedro Martir Mountains, and mesquite beans are gathered by them in many localities.

AGRICULTURE AND STOCK RAISING.

Agriculture.

The soil of Lower California is fertile and yields abundant crops wherever water is available for irrigation. In addition, the temperatures over most of the peninsula are so mild with severe frosts lacking that conditions favor a large variety of temperate, tropical, and subtropical fruits and other crops. The prevailing desert condition, however, combined with the broken and mountainous nature of the country, will always form effective barriers against the agricultural development of more than a small part of the total land area. Millions of acres are covered with an extraordinary growth of desert vegetation which, through a long process of adaptation, is able to survive where agricultural crop growing is an impossibility.

The most important fact to be borne in mind concerning the development of agriculture and grazing in Lower California is that, with the exception of the high mountain tops of the southern and northern ends of the peninsula, practically all parts of that region are subjected from time to time to dry periods of from one to more than five years in extent, during which little or absolutely no rain falls. This necessarily limits successful agriculture to areas which have a permanent water supply, or where such supply can be developed or stored to carry cultivation through successive dry seasons. Another serious drawback to agricultural develop-

FIG. 1.—Palo blanco forest (*Lysiloma candida*) in valley above San Ignacio, on trail to Santa Rosalia.

FIG. 2.—Bark of palo blanco in sacks ready for shipment on coasting vessels at Cape San Lucas village in January, 1906. This bark is used for tanning.

ment in most of the peninsula is the lack of roads and the absence of satisfactory boat service along the coast, thus rendering the marketing of products both costly and uncertain.

Lower California is about 800 miles long and from 30 to more than 100 miles in width. The lands available for agriculture are mainly located in the northern and southern thirds of the peninsula. They are in isolated areas, varying from insignificant patches of 1 or 2 acres below springs, or in the bottoms of canyons to little valleys and open plains bordering the seacoast. The plains, as has already been described, are mainly located along the Pacific coast. The largest single body of agricultural land, however, is that in the delta region of the Colorado, in the extreme northeastern section of the peninsula, and contains approximately 1,500,000 acres which may be irrigated from the Colorado.

The agricultural lands of Lower California may be roughly divided into four main areas according to the origin of the soil. The rich plains in the delta region of the Colorado have been formed by deposits of silt brought down by the Colorado River. The agricultural lands of the northwestern part of the peninsula, and those south of La Paz Bay have been built up mainly from the disintegrated gray granite of which the mountains in those districts are mainly composed. The soil of the great Magdalena Plain is the result of the erosion and disintegration of the volcanic cap and the sandstone base forming the great lava-covered plateau of that region.

Until recent years the agricultural development of the peninsula has been on a small scale and limited mainly to the west side of the mountains in the northwestern part of the peninsula, and to areas south of La Paz Bay. Following the development of the Imperial Valley in California American capital has been successfully promoting agricultural development on a large scale in the rich lands of the delta region of Lower California tributary to the town of Mexicali.

Probably more than 1,000,000 acres of land are available for irrigation in this district fully equal in quality to those of the Imperial Valley. A large part of it is owned by American companies and about 100,000 acres are under cultivation, producing long-fiber cotton, melons, alfalfa, barley, and lesser crops. The crops reported in this district for 1918 include 53,271 bales of cotton, more than 13,500 tons of cotton seed, 25,000 tons of alfalfa, and 15,000 bushels of barley. Experiments in growing rice and sugar cane in this district have been successful, indicating probable future development in these products. The main irrigating canals feeding the Imperial Valley in California are taken out of the Colorado in Lower California territory to supply both areas.

In 1918 an American company leased from the local authorities a large tract of land about Laguna Maquata, on the west side of the Cocopah Mountains. A pumping station was established on the Hardy River and irrigating ditches carried around to this land. Unfortunately, the first planting experiments, which were on a large scale, proved to be on soil so saline that no crops were produced.

A branch of the Southern Pacific Railroad extends from Mexicali, on the international boundary, easterly through the northern part of the delta district, swinging back across the border to join the main line of the railroad west of Yuma, Ariz. Another branch connects this branch road with Volcano Lake. The continued growth and future prosperity of this area is assured.

Another agricultural district, in which the fertile areas are scattered, broken, and far less rich in possibilities than those of the delta region, is that lying west of the Sierra Juarez and San Pedro Martir Mountains, extending from the border of California south along the Pacific coast to beyond San Quintin. This area has three supply points: first, in the north, at Tijuana, on the California border; second, at Ensenada, capital of the northern district; and the third at San Quintin. Within this area are numerous small valleys and plains, including the coastal plains known as the Llano de Hamalu and Llano de San Quintin, which lie along the coast north and south of San Quintin Bay. A considerable total of good lands are available in this district, but no large tracts in any one place except on the two coastal plains mentioned above. More rain falls here than elsewhere in the lowlands of the peninsula, and the numerous small

streams at the bases of the mountains with their underground flow might be made available through storage and pumping to develop a region similar in character to that across the border tributary to San Diego.

The third area is the great Magdalena Plain extending along the Pacific coast north and south from Magdalena Bay. The Llano de Yrais in this area was once the site of a disastrous attempt to establish an American colony and met the fate certain to overtake any ill-judged effort to settle this region without the proper preliminary work. This plain must be developed by means of wells and storage reservoirs to save flood waters from the mountain slopes to the east. Its capacity for production is indicated by the list of crops grown successfully by means of a small well and pump at Matancita (p. 140).

In addition to the foregoing large coastal areas of good land, there are a number of smaller ones where more or less water is available, some of which are now being utilized, as at Ensenada, Guadalupe, and Santo Domingo Valleys in the northwest and Todos Santos, San Jose Valley, the shore of Ventana Bay, La Paz, Loreto, Mulege, and the adjacent plain of San Bruno. Aside from these there are a number of scattered areas throughout the interior, often containing an acre or two and rarely exceeding 1,000 acres in extent. These interior areas number among them the most beautiful occupied oases in the peninsula, such as San Ignacio, La Purisima, and Comondu. Many of the interior locations have been occupied but abandoned owing to drought and the lack of properly developed water resources. The roughness of the country about many of these locations and their isolation are difficulties to be met in their development.

With the development of mining in this region a home market for produce will be formed. Most of the locations, however, can not be developed successfully without some capital for preliminary expenditure.

Further details on the location and extent of the main bodies of agricultural land in the peninsula are given in the accompanying descriptions of the plains and larger valleys. The notes on the "Streams and other Surface Waters," on "Underground Waters" and on "Climate" give information concerning the water resources. The surface water supply now in use is not developed and fully utilized, while at many places underground waters exist at moderate depth, sometimes so near the surface as to be available for subirrigation. Many of the dry stream beds leading down from the interior have water not far underground near the coast. The large number of ruined and abandoned missions and ranches seen along our route was a strong warning against inconsiderate settlement of such areas. It was also evident that without sufficient capital for proper initial expenditure in developing water failure would be certain.

The Indians who occupied Lower California at the time of the discovery practiced no form of agriculture, but subsisted on the natural products of the soil and surrounding waters. The Spanish missionaries very soon began to introduce fruit trees and crops from the mainland of Mexico and the Old World. These introductions included most of the kinds now cultivated in the peninsula. With the exception of the Upper Sonoran district in the northwestern part, practically all of the agricultural land in Lower California is within the Arid Tropical and Lower Sonoran life zones. As a result the climatic conditions are nearly everywhere favorable for such irrigated crops as oranges, lemons, figs, olives, pomegranates, dates, grapes, wheat, barley, and alfalfa. In the southern end, where tropical conditions prevail, coconut palms, bananas, pineapples, and other more strictly tropical species are grown on a small scale.

Citrus fruits thrive wherever they have been tried, but we were informed that the Morelos fruit fly had become established at San Jose del Cabo and perhaps elsewhere in the south. From the northern border south on the west coast to San Quintin these fruits should do well in many places.

A few bananas are grown in the south, but the arid climate prevents their being cultivated on a commercial scale.

Cotton grows well almost everywhere in the lowlands, and in the south, where frosts are slight, this plant becomes a perennial. A large cotton shrub 3 years old was bearing abundantly at Matancita in 1906.

The date palm was introduced by the Jesuit missionaries about 1730 and except in the northwest continues to grow and fruit abundantly wherever tried with a sufficient water supply. Several varieties of dates are grown, all seedlings with large stones. At San Ignacio date palms are extremely numerous and are said to number from 50,000 to 60,000 trees. This is by far the largest number in any one valley, but they are growing generally at the small towns and at many ranches from San Ignacio south. The abundance of date palms at San Ignacio, La Purisima, Comondu, and elsewhere gives an Oriental cast to these beautiful oases. (See Pl. 13, Fig. 2.) There are thousands of acres of land suitable for the cultivation of dates where water can be readily secured, and the long, hot, and arid summer of the peninsula offers ideal conditions for some of the most delicate varieties of this fruit. Dried dates in rawhide bales are packed from San Ignacio to the coast at Santa Rosalia and shipped across to Guaymas and other gulf ports.

Sugar cane is the main crop grown at San Jose del Cabo and at Todos Santos, where several hundred acres of cane fields are cultivated. Brown sugar made into small cakes, called *panocha*, is exported from these places to other parts of the peninsula. This crop is grown on a smaller scale at other localities, expecially at Comondu, La Purisima, Mulege, and San Ignacio.

At La Purisima, Comondu, and some other places in this section an inferior quality of raisins and some wine are made from the mission grape crop, and small quantities of both products are shipped to other localities.

The following crops, aside from cotton, are reported to have been produced in the northern district of Lower California during the season of 1918:

Wheat	kilos	1,800,000	Chick peas	kilos	2,500
Barley	do	150,000	Chili peppers	do	1,500
Beans	do	355,000	Olive oil	liters	1,100
Corn	do	160,000	Jojoba seed	kilos	300
Pinyon nuts	do	3,000	Beeswax (mainly wild)	do	7,000
Almonds	do	2,500	Honey	do	1,600
Walnuts	do	1,500			

The discrepancy between the amount of beeswax and honey produced is due to the fact that most of the latter was consumed. The beeswax is obtained both from bees kept in domestication and from those which have escaped from capitivity and occur throughout a large part of the interior of the peninsula from the northern border south to beyond Calamahue Mission. These wild bees are found from near sea level up to above 8,000 feet on the San Pedro Martir Mountains. On the deserts they live in cavities among the rocks and in certain desert plants, and in the high mountains they occupy hollow trees. In 1905 we found a number of colonies attaching their combs to the underside of the roofs of deserted houses at the base of the foothills in the abandoned settlement on the San Quintin Plain. (See Pl. 34, Fig. 1.)

In January, 1918, as a result of a concession to colonize and exploit the resources of Guadalupe Island, granted to Gen. Manuel Perez Treviño, it was reported that 150 soldiers and their women were located there. It having become evident that there was no arable land, by July, 1919, only 32 soldiers with their followers remained. The island is occupied by large numbers of goats, which for many years have run wild upon it and are reported to number between 30,000 and 40,000. The soldiers remaining on the island are engaged in capturing these animals and delivering them to contractors for 60 cents each. The better grades are being kept and some high-grade Angora bucks have been placed on the island by Gen. Treviño for the purpose of improving the stock. The springs have been cleaned out, huts built for accommodating the people, and it is planned to try to develop the goat industry. In addition to selling goats for the market in San Diego, others are being killed for their skins, tallow, and dried meat, which are shipped to the Mexican mainland.

The following list of localities with their agricultural products shows most of the fruit and crops now being cultivated between the northern border and Cape San Lucas:

La Huerta (east side of San Rafael Valley).—Peaches, apricots, beans, and corn.

Ensenada.—Grapes, peaches, apricots, almonds, walnuts, olives, oranges, lemons, pears, apples, quinces, cherries, pomegranates, figs, wheat, barley, corn, beans, chick peas, potatoes, and most of the ordinary garden vegetables.

Santo Domingo (Young's ranch).—The productiveness of this part of the peninsula is indicated by the fruits in bearing at the ranch of an American named Young, not far from the Santo Domingo Mission, which include small quantities of the following kinds: Oranges, lemons, grapes, pears, apples, quinces, cherries, apricots, peaches, almonds, walnuts, figs, pomegranates, and olives.

San Borja Mission.—Oranges, pomegranates, olives, dates, mission grapes, and alfalfa.

San Ignacio.—Oranges, lemons, pomegranates, olives, black figs, dates (several varieties), mission grapes, sugar cane, wheat, melons, beans, and mescal. (About 1,000 acres cultivated.)

La Purisima and Comondu.—Oranges, lemons, limes, olives, black figs, pomegranates, dates, bananas, mission grapes, sugar cane, cotton, wheat, peas, and beans. (About 1,000 acres cultivated at Comondu and less at La Purisima.)

Loreto.—Dates, oranges, mescal, hides, and dried beef.

San Javier.—Olives, black figs, oranges, bananas, beans, sugar cane, and aguardiente or cane rum. (About 50 acres cultivated.)

Matancita.—Black figs, olives, pomegranates, pears, apples, bananas, grapes of several varieties, cotton, corn, peas, beans, peppers, cabbage, tomatoes, potatoes, carrots, beets, squash, watermelons, muskmelons, and the pulque agave.

San Jose del Cabo.—Black figs, dates, coconuts, coffee, oranges, lemons, limes, pomegranates, aguacate (alligator pear), bananas, pineapples, tobacco, cotton, sugar cane, corn, beans, and other small crops. (About 1,500 acres cultivated.)

Mulege.—Oranges, lemons, sweet limes, dates, olives, pomegranates, figs, mission grapes, bananas, sugar cane, wheat, corn, beans, and others. (About 800 acres cultivated.)

Mexicali (delta of the Colorado).—Alfalfa, barley, Egyptian corn, melons, and cotton.

Stock Raising.

The grazing of both sheep and cattle is fairly successful in the northwestern section of the peninsula from the border south to near San Quintin and from the coast up to the summit of the Sierra Juarez and Sierra San Pedro Martir. In 1918 it was estimated that this area contained from 18,000 to 20,000 cattle. A limited number of cattle also range about the delta of the Colorado. Elsewhere in the peninsula, as might be inferred from the recurrence of series of rainless years, stock growing is a precarious occupation. During a succession of years in which rains occur herds increase abundantly, only to meet disastrous losses through lack of both food and water during the succeeding dry periods, which often continue from three to five years. The Magdalena Bay Co. and others have some thousands of cattle on the Magdalena Plain and the adjacent slopes of the lava plateau, and a more limited number of cattle range in the region south of La Paz. (See Pl. 15, Fig. 1, and Pl. 34, Fig. 2.)

The principal merchant of La Paz, a man well past middle life, informed me that he had always lived in that region and that among his friends were several owners of large cattle ranches whose experience has shown that cattle growing on a large scale in that region was unsuccessful from an economic point of view. He stated that the owners of these ranches during series of favorable years would build up large herds only to lose them during following dry periods. This he had known to occur repeatedly.

SCIENTIFIC EXPLORATIONS.

The first detailed information concerning Lower California was made known through the explorations of the early Spanish missionaries, mainly the Jesuits, who began their labors immediately after the discovery of the peninsula by Cortez in 1535. Since then the main contributions to our knowledge of the coast of the peninsula have come from the work of the U. S. S. *Narragansett* and other American naval vessels, and our knowledge of the interior from the work of American naturalists who have visited it within the last 60 years.

The explorations by American naturalists began when John Xantus landed at Cape San Lucas in 1859, and have been mainly devoted to the study of the plants, reptiles, birds, and mammals. A brief but not exhaustive summary is given below covering most of these expe-

FIG. 1.—Taking honey from bees' nest in small cave near Matomi. The domesticated honey bee has become wild and occurs in the San Pedro Martir Mountains as well as on the deserts far to the south. (Photograph by Dale Bumstead.)

FIG. 2.—Cowboy near Cape San Lucas. The cactus and other thorny plants are so numerous that riders in this region wear leather-covered hats and leather jackets and trousers, and have heavy leather aprons hung on the saddle to cover their legs, as shown in photograph. In addition, a heavy leather apron is hung over the horse's breast to protect it from spines when rushing through jungle after half-wild cattle.

ditions. It is believed that this information will be useful to those studying the collections from this region and will be of historic value. The information has been gathered from a variety of sources including published records and personal communications from some of those who have taken part in the work here recorded. The bibliography following the list includes the titles of most of the published results of these explorations.

1837. F. Deppe.

In the spring of 1837, Herr F. Deppe, who previously had collected numerous types of birds and mammals in eastern Mexico and was then engaged in business in western Mexico, landed at La Paz and traversed the peninsula overland from that point to San Diego, Calif. Lichtenstein published a brief summary of Deppe's observations, among which he states that "The peninsula is poor beyond description in living forms of organic life. Neither reptiles nor insects were seen anywhere * * * ."

Deppe noted a species of woodpecker frequenting the cactuses and says: "In addition to this there were only humming birds and a species of crow which indicated the presence of water in the vicinity. At the watercourses were occasionally found deer and still less frequently hares; with these exceptions no mammals were seen."[1]

The quotations given above exemplify the kind of erroneous statements that gained currency during the early history of the peninsula.

1839. Richard Brinsley Hinds.

The first botanical collection in southern Lower California was made by Surg. Richard B. Hinds, on the voyage of H. M. S. *Sulphur* [2] in 1839. About 150 species were collected, the larger part being new. They were from San Quintin, San Bartolome Bay, Magdalena Bay, and Cape San Lucas. The new species were described by Bentham.[3]

1859. John A. Veatch.

Dr. Veatch sailed from San Francisco in 1859 with a prospecting party which explored Cedros Island in the hope of finding valuable mines. During June, July, and August he collected plants on the island and others on the adjacent mainland, many of which were new. His plants went to the herbarium of the California Academy of Sciences, and his published observations contained much new information concerning the flora of Cedros Island. Some of the more conspicuous species obtained by him were described by Kellogg in "The Hesperian." One of the most remarkable of these, the elephant tree (*Rhus veatchiana* Kellogg), of which Dr. Veatch published a long account, had already been described by Bentham under another generic name.

1859–1861. L. J. Xantus de Vesey.

This naturalist, commonly known as John Xantus, was employed as tidal observer for more than two years, from April, 1859, to the middle of 1861, by the United States Coast Survey at Cape San Lucas. His letters state that he visited San Jose del Cabo, the Sierra Laguna, Todos Santos, La Paz, and Magdalena Bay, in addition to traveling 350 miles up the west coast. Xantus was sent to the cape by the Coast Survey in collaboration with the Smithsonian Institution. He made large collections in several branches of science, notably in plants, invertebrates, reptiles, and birds. At the time of his visit the flora and fauna of this region were practically unknown and his collections furnished numerous types and first drew attention to the peculiar and interesting flora and fauna of the cape district.

1867. The J. Ross Browne Expedition.

On January 5, 1867, J. Ross Browne, accompanied by William M. Gabb and F. von Lohr, landed at Cape San Lucas to explore Lower California in the interest of a colonization company. The party traveled to San Jose del Cabo and thence northerly to Triunfo and La Paz. From the last place they crossed the peninsula to Todos Santos and up the coast to Magdalena Bay. From this point Browne returned to La Paz and the rest of the party under Gabb continued across to Loreto and thence to Comondu, Purisima, Mulege, San Ignacio, Santa Gertrudis, Calmalli, San Borja, Rosarito, Calamahue, San Fernando, San Quintin, Sausal, and Tijuana. The reports on this trip by Browne and Gabb in Browne's "Resources of the Pacific Slope" contains much intercsting information concerning the physical features of the peninsula. During this trip Gabb collected a few plants, several of the cactuses serving as the types of new species.

1870–1890. Edward Palmer.

With the exception of Mr. Brandegee, Dr. Edward Palmer made the most extensive collections of plants ever gathered in Lower California. He collected mainly along the coast and on the islands. His first work in Lower California was on Carmen Island, in the gulf, January 1–2, 1870. Twenty years later he revisited Carmen island and remained a week (November 1-7, 1890). A report on this collection was published by Dr. J. N. Rose.

Dr. Palmer was the first naturalist to collect on Guadalupe Island. He remained there from February to May, 1875, and again visited the island from March 27 to April 3, 1889. During his first visit, in addition to a series of plants he made a small collection of bird skins which furnished the types of several new species and first made known the interesting bird life of this island.

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[1] Abh. Akad. Wiss., Berlin, 1838 (1839), pp. 417–451.
[2] Belcher, Voyage Round the World, 2 vols., 1843.
[3] Botany of the Voyage of H. M. S. *Sulphur*, 1844.

1870–1890. Edward Palmer—Continued.

Early in June and late in December, 1887, he collected at Mulege, and from November 22 to December 20 the same year worked at Los Angeles Bay. These collections, with others from the east side of the gulf, were reported on by Watson. He made a collection of plants at San Quintin in January and February, 1889, and proceeded thence southward to Lagoon Head, where he spent a week. From there he visited Cedros and San Benito Islands, and on March 27 reached Guadalupe Island on his second trip, as already noted. Reports upon these collections were made by Vasey and Rose. On Christmas Day, 1889, he left San Francisco by steamer in company with T. S. Brandegee, who landed at Magdalena Bay, and began his prolonged explorations of the peninsula, while Dr. Palmer continued to Guaymas and thence returned to La Paz, where he collected from January 20 to February 5, 1890. Leaving La Paz he sailed for Santa Rosalia, touching en route at Raza Island, in the gulf, February 12, and at San Pedro Martir Island, Sonora, on the following day. Between February 24 and March 15 collections were made at Santa Rosalia and Santa Agueda, the latter locality 10 miles inland from the port. A list of these collections was published by Vasey and Rose.

1881–1887. Lyman Belding.

The first ornithological work in Lower California after that of John Xantus was done by Lyman Belding, who made two trips to the cape district and to points and islands along the west coast between December, 1881, and the last of March, 1883. Mr. Belding collected several new species and made valuable observations which were published by Mr. Ridgway in the Proceedings of the United States National Museum for 1882 (Vol. V) and 1883 (Vol. VI).

The itineraries for these journeys were as follows: December 15, 1881–March 21, 1882, at La Paz and a short visit to Espiritu Santo Island; April 1–May 17, 1882, at San Jose del Cabo, whence visits were made to Cape San Lucas and other neighboring localities; April 14–26, 1882, Cedros Island; April 28, 1882, Santa Rosalia Bay; May 2–11, 1882, San Quintin; May 16–17, 1882, Coronados Islands; December 15, 1882–March 23, 1883, at La Paz; and in February a visit was made to Triunfo, Miraflores, and the Victoria (=La Laguna) Mountains, 1884 to 1887, several wagon trips were made in winter and spring from Tijuana to Laguna Hanson and return; also to Ensenada, Guadalupe, and San Rafael Valleys, and the northern base of San Pedro Martir Mountains. The collections made in the cape district were sent to the United States National Museum.

1882. C. G. Pringle, C. C. Parry, C. R. Orcutt, and M. E. Jones.

The late C. G. Pringle, who for many years was well known as a collector of plants on the Mexican mainland, visited the northwest coast region of the peninsula from Tijuana southward to Todos Santos Bay, April 5–15, 1882, accompanied by C. C. Parry, C. R. Orcutt, and M. E. Jones.

1882–1886. C. R. Orcutt.

C. R. Orcutt made several short botanical journeys into Lower California and collected the types of various new species, including some cactuses. On some of his trips he accompanied other botanists. A trip was made with C. G. Pringle, C. C. Parry, and M. E. Jones from Tijuana southward near the coast to Todos Santos Bay from April 5–15, 1882; and he was with H. C. Orcutt and C. C. Parry at Todos Santos Bay in January, 1883. In September, 1884, he collected at Santo Tomas. Later he visited the desert about Lake Maquata, between the Sierra Juarez and Cocopah Mountains, and gave an account of this area in the West American Scientist. On one of his longer trips he left San Diego by wagon, March 30, 1886, crossed the boundary at Tijuana, and collected at various localities along the Pacific coast southward to near San Fernando, where, on May 3, he was unable to proceed farther by wagon. He published several papers, including new species, and a nominal list of plants with no definite localities.

1885. Edward Lee Greene.

Dr. Greene sailed from San Diego in April, 1885, and visited the Coronados, Todos Santos, Cedros, and Guadalupe Islands, and San Quintin on the mainland, whence he returned to San Diego about the middle of May. The results of this botanical trip were published by him in several papers, adding 15 species to the flora of Guadalupe Island, seven of which were described as new.

1885–1894. Walter E. Bryant.

We are indebted to the repeated expeditions of Bryant and his subsequent publications of results for much of our knowledge of the bird life of Lower California and the islands on its western coast.

In January, 1885, he made a brief visit to Guadalupe Island, and December 16 of the same year again landed there, where he remained until the 1st of April, 1886. The results of this trip appeared in the best paper yet published on the birds of Guadalupe. The work on Guadalupe was his personal venture, but subsequently he conducted a number of expeditions to the cape district and the coastal islands in the interest of the California Academy of Sciences as set forth under the account of the expeditions of that institution. Bryant collected mainly birds, but also secured numerous reptiles and mammals and a few plants when he was not accompanied by a botanist. His main collections forwarded to the California Academy of Sciences, were destroyed by fire in April, 1906.

1887. Brewster Expedition.

One of the most important ornithological explorations ever made in Lower California was that organized by William Brewster. The field work was done by M. Abbott Frazar, who landed at La Paz January 24, 1887, to collect birds in the cape district. He remained there most of the year, visiting a number of localities and making a large and extraordinarily fine and complete collection of the birds of this area. These specimens are in the Brewster collection and include the types of a number of new species and subspecies described by

1887. Brewster Expedition—Continued.

Brewster. They also served as the basis for the admirable volume on the "Birds of the Cape Region of Lower California," by the same author.

Mr. Frazar's itinerary, all in 1887, was as follows: January 24–February 26 and March 16–April 7, at La Paz; February 26–March 15, at Espiritu Santo, San Jose, Montserrat, and Carmen Islands, and a brief visit to the mainland opposite Carmen Island and to Loreto; April 11, June 10–July 2, and December 4–11, at Triunfo; the last of April–June 9 and November 27–December 4, in the Sierra de la Laguna; July 4–30, at San Jose del Rancho (Pierce's ranch), 15 miles southeast of Triunfo; last of August–November 12, at San Jose del Cabo.

1887–1899. A. W. Anthony.

A large part of our knowledge concerning the birds and mammals of northern Lower California and the islands off the west coast of the peninsula is the result of extended and careful field work done by A. W. Anthony from 1887 to 1899. During this period he made numerous overland trips and visited all the islands on the west coast, including Guadalupe. Numerous papers on the results of this work with descriptions of new species of birds and mammals have been published by Anthony and others. The large and valuable collection of birds gathered during these years is now in the Carnegie Museum, Pittsburgh; the mammals are mainly in the National Museum at Washington and in the American Museum of Natural History, New York.

The data for the following brief summary of his field work have been supplied by Mr. Anthony: March, 1887, landed at Ensenada and traveled overland to San Quintin, which was his base camp for more than a year. From this point he visited San Fernando and Valladares in the interior and San Martin, San Geronimo, and Cedros Islands offshore, besides making several landings along the coast south of San Quintin. During 1889 he was located at Valladares, whence several short trips were made into the San Pedro Martir Mountains, including a visit there in April and May in company with C. H. Townsend, when a number of new species of birds and mammals were collected. In the spring of 1893 about six weeks, including the month of May, were spent in these mountains and the results were published in Zoe. In December, 1893, he spent a week at the copper mines near San Fernando, and in 1894 he returned there and remained from the middle of February to the 1st of July.

Anthony's first visit to Guadalupe Island occupied 10 days late in May, 1892; he spent a week there in August, 1896, and another week in April, 1897.

In 1896 he chartered a schooner and, in company with Horace Gaylord, spent from the last of July to early September along the coast of the peninsula, including the San Benitos and other coastal islands, south to Turtle Bay.

In 1897 he purchased a sealing schooner and, accompanied by R. C. McGregor, H. B. Kaeding, T. S. Brandegee, and A. L. Stockton, explored the west coast of the peninsula and the coastal islands, also including Guadalupe, as far as San Jose del Cabo, where Brandegee landed and the rest of the party visited Socorro, Benedicte, and Clarion Islands southwest of Cape San Lucas. Plants were collected, mainly by Stockton, throughout this expedition.

On February 25, 1899, Anthony sailed from San Francisco in a schooner for the west coast of Mexico and Central America. He was accompanied by R. H. Beck, R. C. McGregor, H. B. Kaeding, Chase Littlejohn, and H. M. Gaylord. The expedition stopped and made collections of birds on several islands along the coast of Lower California. On March 16 the schooner was wrecked and became a total loss on the coast about 30 miles north of Magdalena Bay.

1888. J. G. Lemmon.

In May, 1888, J. G. Lemmon collected plants in San Rafael Valley and at Hanson's ranch on the upper slope of the Sierra Juarez.

1888–1889. Charles F. Pond.

Lieut. Charles F. Pond, of the U. S. S. *Ranger*, collected plants at several localities during a survey of the shores and islands of the peninsula and made several visits to the San Benito Islands between December, 1888, and February, 1889. He also visited Cedros Island in the same winter and made a small collection, which formed the basis of a supplementary list of Cedros Island plants published by Greene. He made his most important collections, however, on the low plains around the southern shore of San Bartolome Bay in March, 1889.

1888–1906. California Academy of Sciences Expeditions.

The California Academy of Sciences has devoted much attention to the scientific exploration of Lower California, especially between the years 1888 and 1894. This work was mainly in the southern half of the peninsula and on the outlying islands. General collections were made, including fine series of plants, shells, insects, and other invertebrates, reptiles, birds, and mammals, but practically all these collections were destroyed by the fire following the San Francisco earthquake in April, 1906. Numerous papers have been published on the results of this work in the Proceedings of the California Academy of Sciences, in Zoe, and in other scientific publications. A good review of these expeditions is published in the Proceedings of the California Academy of Sciences for 1895. A brief summary is given below:

1888. In March, 1888, W. E. Bryant landed at Magdalena Island and traveled to San Jorge by water and thence overland across the peninsula through Comondu and La Giganta to Loreto, on the gulf coast. The return

1888–1906. CALIFORNIA ACADEMY OF SCIENCES EXPEDITIONS—Continued.

was made along the same route, but included the additional localities of San Gabriel and San Juan. Birds were the main object of this visit, but some plants and mammals were also collected.

1889. On January 11, 1889, the second expedition landed at Magdalena Bay. W. E. Bryant and an assistant, Charles D. Hains, represented the academy and made general collections of invertebrates, reptiles, birds, and mammals. T. S. Brandegee accompanied this party and worked independently on the botany of the region traversed. The party journeyed north to San Jorge, La Purisima, Comondu, and back to Magdalena Bay. From there they again returned to Comondu and traveled thence northward through La Purisima, San Ignacio, Calmalli, San Borgia, San Fernando, and El Rosario to San Quintin, where they arrived in May and sailed thence to San Diego. This expedition was extremely fruitful in results, especially in reference to the plant and bird life of the peninsula.

1890. In September of this year W. E. Bryant for the academy, and T. S. Brandegee on his own account, landed at San Jose del Cabo and traversed the country through to Miraflores, the Sierra San Francisquito, Triunfo, and La Paz, where the expedition ended in October.

1892. During March, April, and May of this year the cape district was again visited by a party from the academy, consisting of W. E. Bryant and Gustav Eisen, accompanied by T. S. Brandegee on his own account. They landed at San Jose del Cabo and visited Cape San Lucas, Agua Caliente, Miraflores, Sierra San Francisquito, returned to San Jose, and went by steamer to La Paz and thence to California.

1893. During September and October Gustav Eisen traveled from San Jose del Cabo across the Sierra El Taste to Pescadero and Todos Santos, then returned through Cape San Lucas to San Jose and thence to Miraflores and through the Sierra San Francisquito and Sierra Victoria to Todos Santos again. During part of this expedition Dr. Eisen was accompanied by Mr. and Mrs. T. S. Brandegee.

1894. During September, October, and November Gustav Eisen and Frank H. Vaslit visited San Jose del Cabo and traveled thence through Santa Anita, Miraflores, La Palma, the Sierra San Lazaro, El Taste, and back to San Jose. From this point they traveled by way of Santiago, San Bartolo, and Triunfo to La Paz.

1903. April 25 the schooner *Mary Sachs* (31 tons) sailed from San Francisco on a scientific expedition to the Revillagigedo Islands, off the west coast of Mexico, in the interest of the California Academy of Sciences. The expedition was in charge of R. H. Beck, who was specially interested in birds. The other members of the party were A. S. Bunnell, birds; E. W. Gifford, shells; F. E. Barkelew, plants; C. H. Marks, jr., anthropology. During April and May the expedition made brief stops to collect at Ensenada, on the mainland of Lower California, and at the adjacent San Martin, San Benito, and Natividad Islands. Fine series of specimens were collected during this expedition, which returned to San Francisco, August 13. These collections were all destroyed by fire in April, 1906.

1905–6. June 25, 1905, the schooner *Academy* (114 tons) sailed from San Francisco on a scientific expedition to the Galapagos Islands, from which it returned November 29, 1906, with extraordinarily rich collections. The expedition was in charge of R. H. Beck, who collected birds and reptiles and was accompanied by E. W. Gifford, birds; J. S. Hunter, birds and mammals; J. R. Slevin, reptiles; E. S. King, reptiles; F. X. Williams, insects; Alban Stewart, plants; and W. H. Ochsner, shells and fossils. On its way south in July the expedition made brief stops and small collections at Ensenada, Lower California, and on the adjacent San Martin, San Geronimo, San Benito, Cedros, and Natividad Islands.

1889–1902. TOWNSHEND STITH BRANDEGEE.

Mr. Brandegee has done more than any other botanist, both by field work and in published results, to make known the flora of Lower California. Most of his field work was carried on in connection with expeditions of the California Academy of Sciences, which he accompanied at his own expense. In addition to these expeditions, detailed elsewhere, he visited the coast region adjacent to Magdalena Bay in January, 1890, working from Matancita to Todos Santos and thence to the Sierra de la Laguna and La Paz, where the journey ended in February.

In the early part of 1893 Mr. Brandegee turned his attention to northern Lower California. During May he crossed the boundary to Tijuana and traveled southward along the coast past Ensenada and as far as Cape Colnett. From this vicinity a side trip was made into the San Pedro Martir Mountains and back over the same route to Tijuana. In September and October of the same year he returned to the cape district. From San Jose del Cabo a trip was made with Mrs. Brandegee to El Taste, and various localities, including the high mountains, were revisited.

In February, 1897, he cruised with A. W. Anthony in a schooner along the west coast and adjacent islands. They stopped at Ensenada and then in turn at the islands of Todos Santos, San Martin, San Geronimo, Guadalupe, San Benito, Cedros, and Natividad, and at San Bartolome Bay. Continuing farther south they touched at San Roque and Ascencion Islands and landed at San Jose del Cabo, where Brandegee left the boat. In September, 1899, and during the same month in 1902, he made other collections at a number of localities in the cape district. The Brandegee collection of plants is now in the herbarium of the University of California.

1892–1893. F. FRANCESCHI.

In December, 1892, and January, 1893, F. Franceschi made a small collection of plants on Guadalupe Island. Very few species were added to those already known, but the list published by the collector includes interesting notes on the condition of the flora as affected by the goats introduced on the island many years before.

1892–1894. Gustav Eisen.

Dr. Gustav Eisen made several scientific trips to Lower California, mainly as member of expeditions sent out by the California Academy of Sciences. These expeditions are noted elsewhere. In addition he spent the period from June to August, 1894, in the middle parts of the peninsula, landing at Loreto and traveling through Comondu, San Vicente, La Purisima, Guajademi, San Ignacio, and San Angel, and thence across the Vizcaino Desert to Cerro Prieto, La Huerta, and San Andres on the coast south of San Bartolome Bay and to the placer mines of the adjacent Sierra Pintada.

In addition to a number of scientific papers based on collections made on the peninsula, Dr. Eisen published two important articles, referred to elsewhere, on the geography and geology of southern Lower California with the best maps of that region which have yet appeared.

1893. Stowell and Lunt Expedition.

J. C. Stowell and S. C. C. Lunt made a collecting trip from Ensenada to the higher parts of the San Pedro Martir Mountains during June and July, 1893. Their collections of reptiles, birds, and mammals are in the Museum of Stanford University.

1894. Edgar Alexander Mearns.

The late Col. Edgar Alexander Mearns, U. S. Army, while attached to the International Boundary Commission as medical officer and zoologist, made extensive collections of mammals, birds, reptiles, amphibians, fishes, plants, and other specimens of natural history in Lower California between March and July, 1894. His investigations included an exploration of the Lower Colorado River and the lower part of the Salton River from March 23 to early May, and trips to Nachoguero Valley from June 1 to 7, to the San Isidro Range from June 28 to July 3, and to the Tijuana Valley, July 9 to 20, besides incidental work conducted south of the boundary line at various other points. Some of the results of this work are published in Part I of Col. Mearns's report of the mammals of the Mexican boundary. The collections resulting from this work are in the United States National Museum.

1895. Leon Diguet.

During 1895 a few plants were collected by Leon Diguet on Catalina Island and perhaps at other localities in the Gulf of California. The most interesting result of his work was the discovery on Catalina Island of the giant *Echinocactus* bearing his name.

1895–1915. Biological Survey Expeditions.

1895. March 31, 1895, J. Ellis McLellan arrived at San Jose del Cabo to collect the birds and mammals of that region for the Biological Survey. From this point he visited Cape San Lucas and Santa Anita and proceeded overland through Miraflores, the Sierra Victoria, San Felipe, Todos Santos, and Triunfo to La Paz, where he arrived in June. From this base he visited the gulf islands of San Jose, Carmen, Espiritu Santo, and Ceralvo, and closed his field work in September, 1895.

1896. In December, 1896, Frank Stephens spent about two weeks collecting birds and mammals for the Biological Survey between the delta of the Colorado River and the Cocopah Mountains.

1905–6. Between March, 1905, and February, 1906, E. W. Nelson and E. A. Goldman explored the peninsula throughout its extent in the interest of the Biological Survey as set forth in this report. Collections were made of plants, fresh-water fishes, reptiles, birds, and mammals, all of which are in the United States National Museum.

1915. In May and June, 1915, Luther J. Goldman visited the delta region of the Colorado River in Lower California, where collections, mainly of breeding birds, were made at various localities from Volcano Lake to the mouth of the river.

1896. W. W. Price Expedition.

In 1896 Mr. Price sent a party to southern Lower California to collect birds and mammals. Dane Coolidge was in charge and was assisted by Loye Miller and J. F. Abbott. They arrived at San Jose del Cabo May 9, and soon located at Santa Anita ranch, where they remained for six weeks. Practically all of July was spent at La Laguna, on the Sierra de la Laguna. August was passed in the low country, mainly at San Jose del Cabo, after which the party returned to San Francisco.

This expedition appears to have been purely commercial and the collections were sold and widely distributed, most of the mammals going to the British Museum. Among these collections were the types of several species of mammals.

1898–1901. C. A. Purpus.

Dr. C. A. Purpus was shipwrecked at Lagoon Head in the spring of 1898. He collected at Santo Domingo, near Lagoon Head, and, journeying to Calmalli and San Pablo, made further collections in the central part of the peninsula. Several of his plants were described by Brandegee as new species. He collected plants at San Jose del Cabo in 1901.

1902. Field Museum of Natural History Expedition.

February 28, 1902, Edmund Heller arrived at Ensenada to collect mammals in the northern part of the peninsula for the Field Museum of Natural History. During March and April he worked south to Santo Tomas and easterly through Salado Canyon and Trinidad Valley to San Felipe Bay on the gulf coast, returning over the same route to Ensenada.

1902. FIELD MUSEUM OF NATURAL HISTORY EXPEDITION—Continued.

May 7 he again left this place and journeyed through Trinidad Valley and along the west side of the San Pedro Martir Mountains to San Antonio ranch and Rosarito. Thence he crossed these mountains to Matomi and Rosarito Divide and down to San Quintin, whence he made a short visit to the lower San Simon River. The last of July he returned to the San Pedro Martir Mountains and traversed their higher parts, visiting Santa Eulalia, Santa Rosa, La Grulla, Vallecitos, and Piñon. He left the mountains from the latter point in October and crossed Trinidad Valley to Alamo and thence passed through Ojos Negros in San Rafael Valley to Hanson Lagoon on top of the Sierra Juarez. From this point the top of these mountains and a part of the neighboring eastern slope were explored, field work ending about the middle of November.

This was the first attempt to make a detailed and thorough collection of mammals in any part of Lower California, and the report on the collection by D. G. Elliot, including quotations from Heller's field notes, was a valuable contribution to our knowledge of the physical conditions and mammal life in the northern part of the peninsula.

1903. J. H. BATTY.

In the fall of 1903, J. H. Batty collected birds for the American Museum of Natural History in the country lying inland from San Quintin. During October he visited San Simon and the San Pedro Martir Mountains, and during November continued work in these mountains at Rosarito, San Jose Canyon, Fresnal Canyon, and Santa Eulalia.

1904–1905. DANIEL TREMBLEY MACDOUGAL.

In January and February, 1904, Dr. MacDougal made a boat trip from Yuma, Ariz., to San Felipe Bay, Lower California, where a collection was made in the interest of the New York Botanical Garden. In March and April of the following year, in the interest of the Carnegie Institution, and accompanied by E. A. Goldman of the Biological Survey, he again descended the Colorado River, the objective point being the Cocopah Mountains, which were reached by ascending Hardy River. A few plants were obtained by MacDougal along the route, and as many species as the time and season would permit were taken by him in the Cocopah Mountains. This collection was also added to the herbarium of the New York Botanical Garden. Goldman, meanwhile, devoted his attention to the fauna of the region, the collection secured being sent to the United States National Museum.

1905. PHILADELPHIA ACADEMY OF NATURAL SCIENCES EXPEDITION.

During February, 1905, Mr. S. N. Rhoads, in company with H. E. Wilder and a guide, made a boat trip to the delta of the Colorado River in the interest of the Philadelphia Academy of Sciences. They descended to the mouth of Hardy River, which they then ascended to the base of the Cocopah Mountains. Thence they traveled overland to Calexico on the California border. This trip was mainly to collect specimens of the birds and mammals, of which annotated lists were published in the Proceedings of the Academy of Natural Sciences of Philadelphia for 1905.

1906–1910. THAYER MUSEUM EXPEDITIONS.

During the years named above John E. Thayer sent the well-known field naturalist W. W. Brown to various parts of Lower California and adjacent islands to collect birds and a few mammals. Several papers on the results of this work have been published by Thayer and Bangs, mainly in the Condor. The birds collected are in the Thayer Museum and the mammals in the Museum of Comparative Zoology. Brown's work was distributed as follows: Cedros, San Benito, and Guadalupe Islands in sequence from April to June, 1906; San Quintin, July, 1906, and January, 1917; Rosario, October and November, 1906, and February, 1907; San Andres, Rosarito, Santana, and San Javier, February to April, 1907; La Paz, February to April and September, 1908; also March to June, 1910; San Jose Island, June, 1908, and February, 1909; Pichilinque and Puerto Balandro, May, 1908; Sierra de la Laguna and Triunfo, August and September, 1908; El Sauz and Miraflores, November and December, 1908; Santiago and Eureka, November, 1908, to January, 1909; El Callo Island, February, 1909; San Ildefonso Island, April, 1909; near Loreto, Comondu, and La Purisima, April and May, 1909; Espiritu Santo Island, June, 1910.

1911. AMERICAN MUSEUM OF NATURAL HISTORY EXPEDITION.

During the spring of 1911, a party on the United States Bureau of Fisheries steamer *Albatross* made a biological reconnaissance of the coast and bordering islands of Lower California in the interest of the American Museum of Natural History. The expedition was in charge of Dr. C. H. Townsend, who devoted special attention to reptiles and fishes and who was accompanied by the following scientific corps: Dr. J. N. Rose, botany; Dr. Paul Bartsch, invertebrates; H. E. Anthony, mammals; and P. I. Osburn, birds.

The steamer left San Diego, Calif., February 25, and proceeded to Guadalupe Island, where it remained several days and discovered a herd of living sea elephants, a species previously reported to be extinct. Young sea elephants were captured and taken to San Diego to be shipped to New York. March 7, the party again left San Diego and steamed down the coast, stopping at practically all of the islands along the west coast, as well as at some points on the mainland, including Magdalena Bay and Cape San Lucas. Thence the boat proceeded into the Gulf of California, touching at La Paz and Mulege and on most of the islands of the Gulf north to Angel de la Guarda and Tiburon, as well as at Guaymas on the Sonora shore. The expedition was extremely productive in material, fine series of plants, invertebrates, reptiles, fishes, birds, and mammals being collected. These results added much to our knowledge of distribution, in addition to discovering numerous

1911. American Museum of Natural History Expedition—Continued.
new species of plant and animal life. The expedition ended when the *Albatross* arrived at San Francisco the last of April, 1911.

The localities visited during this expedition, with inclusive dates, follow: Guadalupe Island, March 2 to 4; East and West San Benito Islands, March 9; Cedros Islands, March 10–12; San Bartolome Bay, March 13–14; San Roque Island, March 15; Abreojos Point, March 16; Santa Maria Bay, March 18; Santa Margarita Island, March 19–20; Mangrove Island, March 20; Magdalena Island, March 21; Cape San Lucas, March 23–24; San Jose del Cabo, March 25–26; Pichilinque Island, March 27; on peninsula near Pichilinque Island, March 28; La Paz, March 29; San Jose Island, March 30–31; Cayo Island, March 31; Agua Verde, April 1–2; Carmen Island, April 2–3; Mulege, April 4; Concepcion Bay, April 5–7; San Francisquito Bay, April 9–10; Angel de la Guarda Island, April 10; Tiburon Island, April 11; Seal Island, April 13; San Esteban Island, April 13–14; Catalina Island, April 16; Santa Cruz Island, April 16; Pichilinque Island, April 17; Espiritu Santo Island, April 18–19; Ceralvo Island, April 19.

BIBLIOGRAPHY OF LOWER CALIFORNIA.

This bibliography is not complete but includes the titles of most of the general works and scattered articles containing original matter relating to the peninsula, its history and physical character, and the attempts at colonization within its borders. In addition, it contains most of the publications on botany and vertebrate zoology except those on the fishes. But few papers on invertebrate zoology have been included, this subject being outside the field of the present work.

1686. Otondo y Antillon, Isodoro. Some Discoveries Made in the Island of California in the Year 1683. <A Relation of the Invasion and Conquest of the Floridas. London, 1686; published in Paris in 1685.
Not seen.

1705. . . . Letters Edifiantes et Curieuses, etc., V. Recueil, 12mo., pp. 1–287, with map.
Contains a translation of Padre Piccolo's memoir on missionary work in Lower California to the Royal Council at Guadalajara.

1708. Piccolo, Francis Maria. An Extract of a Memoir Concerning the Discovery of a Passage by Land to California with a Map and Description of the Country. Presented to the Royal Council of Guadalaxara in Mexico, by Francis Maria Piccolo. Taken from the Letters of the Missionary Jesuits, printed at Paris. With map by Padre Eusebius Francis Kino. <Philos. Trans., XXVI, No. 318, Nov.–Dec., pp. 232–240. London.
This is an English translation of the original French edition printed in Paris. The original memoir is dated Guadalaxara, Mexico, February 10, 1702. Piccolo's account of the mountain sheep is one of the sources of the subsequent notices of this animal by Venegas, Clavijero, and others, and is the first account of these animals from America.

1712. Rogers, Woodes. A Cruising Voyage Round the World [from 1708–11]. Pp. 428, with appendix and maps, 8vo, London.
During this voyage the west coast of Mexico, the Tres Marias Islands, and southern Lower California were visited during 1709–10. There are a few notes on natural history.

1715. Bernard Jean Frederic. Recueil de Voiages au Nord, etc. 12mo., Vol. III, pp. 1–340.
Contains brief translations of a few of the Spanish accounts of explorations and missionary work in Lower California.

1723. Torquemada, Juan de. Primera [segunda, tercera] parte de los veinte i un libros rituales i monarquia indiana, con el origen y guerras de los Indios Occidentales, de sus poblaçones descubrimiento, conquista, conuersion y otra cosas marauillosas de la mesma tierra. 3 vols., quarto, Madrid, 1723 [original ed. Seville, 1615].
Contains a history of the Indians of Mexico and of the conquest, with an account of the missions and explorations in upper and Lower California, especially the voyages of Vizcaino along the west coast of the peninsula (vol. 1). This work is usually cited under an abbreviated title as the "Monarquia Indiana."

1726. Shelvocke, Capt. George. A Voyage Round the World by Way of the Great South Sea. 8vo., pp. 1–468, with cuts. London.
Contains an account of a visit to the southern end of Lower California in August, 1721, and a brief account of the peninsula, including an extremely favorable statement concerning the character of the natives encountered at Cape San Lucas.

1754. Venegas, Miguel. El Apostol Representado en la vida del V. P. Juan Maria Salvatierra. Pp. 316, 8vo. Mexico.
This account of the life of Salvatierra includes his work in Lower California but has little of interest.

1757. ————. Noticia de la California. 3 vols., pp. 240, 436, 564, with plates and maps, 8vo. Madrid.
A general account of the early settlement and physical character, people, and natural products of Lower California. The margin of the map in the first volume contains the first published illustration of an American mountain sheep. In appendices to vol. 3 are accounts of voyages along the coasts of the peninsula by Vizcaino, 1602; Woodes Rogers, 1710; Lord Anson, 1740; and Padre Fernando Consag, 1746.

1759. ————. A Natural and Civil History of California. 2 vols., pp. 387, 455, 8vo. London.
A translation of the "Noticia de la California," published in 3 vols., in Madrid, 1757. The natural history of Lower California is treated in vol. 1, pp. 32–52.

1762. LOCKMAN. . . . Travels of the Jesuits into Various Parts of the World, etc. 8vo., Vol. I, pp. 1–487. London.
Contains a few letters and reports giving interesting details of the work of Padre Piccolo and other early missionaries in Lower California. Mainly concerns other parts of the world.

1772. BAEGERT, JAKOB. Nachrichten von der Amerikanischen Halbinsel Californien. Pp. 358, pl., and map, small 8vo. Mannheim.
Baegert was a missionary stationed at the mission of San Luis Gonzaga and gives an account of the physical character, inhabitants, early missions, and natural history of the peninsula, mainly the southern part, up to 1767.

1778. D'AUTEROCHE, CHAPPE. A Voyage to California to Observe the Transit of Venus, etc. 8vo., pp. 1–215. London.
A brief account of a voyage made in 1768–69. The party crossed Mexico from Vera Cruz to San Blas and sailed thence to San Jose del Cabo where it landed and observed the transit of Venus as planned. The most notable incident was the virulent epidemic of yellow fever experienced at San Jose del Cabo.

1811. HUMBOLDT, ALEXANDER. Essai Politique sur le Royaume de la Nouvelle-Espagne. 2 vols., with atlas of charts and maps, folio. Paris.
These volumes form Part III of the "Voyage de Humboldt et Bonpland." In Vol. I, pp. 308–327, is a brief account of Lower California, with a reference to mountain sheep near Comondu and to antelope near Monterey, Calif. An octavo edition of this work without the charts and maps was published the same year in Paris.

1829. HARDY, LIEUT. R. W. H. Travels in the Interior of Mexico in 1825, 1826, 1827, and 1828. Pp. 540, with plates and map, 8vo. London.
This narrative covers the country from the City of Mexico to the mouth of the Colorado River and the shores of the Gulf of California, The author investigated the pearl industry of the gulf in the interest of an English corporation.

1832. MORRELL, BENJAMIN, Jr. A Narrative of Four Voyages to the South Sea, North and South Pacific Ocean, etc. Pp. 492, 1 plate, 8vo. New York.
Contains an account of visits to Guadalupe, Socorro, and other islands and the west coast of upper and Lower California to a point north of San Francisco during March to June.

1834. DUHAUT-CILLY, AUGUSTE. Voyage Autour du Monde. 2 vols., pp. 409, 438, 8vo. Paris.
Narrative of the voyage of the *Heros*, 1826–29, including a visit to the west coast of Mexico, the cape district of the peninsula, and upper California. The naturalist Dr. Botta accompanied this trading voyage.

1839. FORBES, ALEXANDER. California: A History of Upper and Lower California. Pp. 352, with maps and plates, 8vo. London.
Contains a brief summary of the history of both areas; the Lower California part appears to have been taken mainly from Venegas.

1839. LICHTENSTEIN, H. Beitrag zur ornithologischen Fauna von Californiau. <Abh. Akad. Wiss. Berlin, für 1838, pp. 417–451.
Contains a summarized account of an overland journey by F. Deppe in the spring of 1836 from Loreto up through the peninsula to San Diego, California, with brief notes on the plant and animal life observed.

1840–55. DU PETIT-THOUARS, ABEL. Voyage Autour du Monde sur la Frégate *La Venus* Pendant les Années, 1836–1839. 10 vols., 8vo, with folios of plates. Paris.
The narrative is contained in the first four volumes with three folios of plates [1840–43]. The fifth volume with one folio of plates [1855] contains papers on mammals by Geoffroy Saint Hilaire and birds by Prevost and Des Murs. The narrative describes visits to Magdalena Bay and points in the cape district of the peninsula and to Guadalupe Island.

1843. BELCHER, Sir EDWARD. Narrative of a Voyage Round the World Performed in H. M. S. *Sulphur* During the Years 1836–1842. 2 vols., pp. 387, 474, with maps and plates, 8vo. London.
Includes brief notes on the west coast of Mexico and Lower California. Richard B. Hinds was surgeon and naturalist of this expedition.

1844. BENTHAM, GEORGE. The Botany of the Voyage of H. M. S. *Sulphur*, under the Command of Capt. Sir Edward Belcher, During the Years 1836–1842. Edited and superintended by Richard Brinsley Hinds, Esq., surgeon, R. N., attached to the expedition. The botanical descriptions by George Bentham, Esq. Pp. 195, 60 plates, quarto. London.
The *Sulphur* on her her voyage around the world visited San Quintin, San Bartolome Bay, Magdalena Bay, and Cape San Lucas, where about 150 species of plants were collected by the surgeon, Richard B. Hinds. This being the first collection from southern Lower California, the larger part of the plants were new to science.

1844. DE MOFRAS, DUFLOT. Exploration du Territoire de l'Orégon, des Californies et de la mer Vermeille. 2 vols., pp. 521, 514, with plates, 8vo. Paris.
An account of a journey made during the years 1840–42, with some notes on fur-bearing and other large mammals.

1850. BUFFUM, Lieut. E. GOULD. Six Months in the Gold Fields in Upper and Lower California. Pp. 172, small 8vo. Philadelphia.
An account of conditions in the gold-mining districts of California, with a brief account of the occupation of La Paz by the Seventh Regiment of New York Volunteers, which landed there July 21, 1847, and held possession of the peninsula to the close of the Mexican War.

1850. RYAN, WILLIAM REDMOND. Personal Adventures in Upper and Lower California in 1848–1849. 2 vols., pp. 347, 413, with plates, small 8vo. London.
Contains notes on conditions at southern end of Lower California in 1848.

1851. . . . Madame la Comptesse de, Histoire Chrétienne de le Californie. 12 mo., pp. 262. Plancy.
A brief account of the natives of Lower California and the work among them of the principal Spanish missionaries.

1852. Clavigero, Francisco Javier. Historia de la Antigua ó Baja California, Mexico. Pp. 252, 3 plates, quarto. Mexico [first published in Italian at Venice 1789].

A translation from the Spanish edition into English was made by A. G. Randall and extracts published in the appendix to Browne's Resources of the Pacific Slope, pp. 155–172 (1887). This work contains some notes on the animal and plant life of Lower California.

1853. Seemann, Berthold. Narrative of the Voyage of H. M. S. *Herald* During the Years 1845–51. 2 vols., pp. 22, 302, with plates and map, 8vo. London.

Contains a brief account of the coasts of Lower California and western Mexico with Seemann's trip inland from Mazatlan to Durango City and return.

1854. Reid, J. M. The Ensenada. <National Magazine, Vol. 4, No. 6, pp. 502–505, June.

Contains interesting notes concerning the capture of La Paz and other ports of Lower California by the filibuster Walker, in 1853, by a member of the expedition.

1855. Leconte, John. Account of some Volcanic Springs in the Desert of the Colorado. <Silliman's American Journal of Science, 2d ser., XIX, pp. 1–6, May.

A brief popular account of a trip from the coast range across the Colorado Desert to the mud "Volcanos" near Volcano Lake. This is the first report on these "volcanos" by a scientific observer.

1859. Baird, Spencer F. Notes on a Collection of Birds made by Mr. John Xantus at Cape Saint Lucas, Lower California, and now in the Museum of the Smithsonian Institution. <Proc. Acad. Nat. Sci., Philadelphia, November, pp. 299–306.

Contains original descriptions of *Cardinalis igneus*, *Pipilo albigula*, *Chamaepelia passerina* var. *pallescens*, and the name *pertinax* proposed for the cape region *Myiarchus* if it proves to be distinct; 42 species given in the list. Also mentions two bats (*Macrotus californicus* and *Vespertilio pallidus*) from the same locality.

1859. Lassepas, Ulises Urbano. De la Colonizacion de la Baja California y Decreto de 10 de Marzo de 1857. Primer memorial, Mexico. 8vo, pp. 250.

A brief account of the settlement of Lower California from the time of its discovery until 1857. In addition to the account of the colonization, including the land grants to individuals covering parts of this region, the work has chapters on the physiography, resources, and civil government of the peninsula. It is a valuable contribution to the history of Lower California.

1859. Xantus, John. Descriptions of Supposed New Species of Birds from Cape Saint Lucas, Lower California. <Proc. Acad. Nat. Sci., Philadelphia, November, pp. 297–299.

Contains original descriptions of *Picus lucasanus*, *Campylorhynchus affinis*, *Harporhynchus cinereus*, *Brachyrhamphus hypoleucus*.

1860. Kellogg, A. The Tree Primrose or False Fuchsia. <The Hesperian, IV, No. 1, pp. 1–2, with plate, March.

Original description of the handsome red-flowered shrub *Oenothera arborea* Kellogg (*Xylonagra arborea*).

1860. ———. Cedar Island Juniper. <The Hesperian, IV, No. 1, pp. 2–4, March.

Original description of *Juniperus cedrosiana* Kellogg (=*Juniperus californica*). Reported as abundant in canyons at about 700 feet elevation, on the east side of Cedros Island.

1860. ———. *Idria columnaris*. <The Hesperian, IV, pp. 101–102, with plate, May.

Original description of this remarkable species, known only from Lower California.

1860. Lawrence, G. N. Descriptions of Three New Species of Humming Birds of the Genera *Heliomaster*, *Amazilia*, and *Mellisuga*. <Ann. Lyc. Nat. Hist., New York, VII, p. 109, April.

Contains original description of *Amazilia xantusi* (=*Basilinna xantusi*) from Cape San Lucas.

1860. ———. Description of a New Species of Bird of the Genus Phaeton, also a New Species of Humming Bird of the Genus Heliopædica. <Ann. Lyc. Nat. Hist. New York, VII, p. 145, April.

Describes *H. castaneocauda* (=*Basilinna xantusi*) from Cape San Lucas.

1860. Veatch, John A. About Cerros Island. <The Hesperian, III, No. 6 pp. 529–534, with plate, February.

A brief popular account of the island and its fauna and flora based on the author's visit there in 1859.

1860. ———. *Rhus veatchiana* Kellogg: Veatch's Sumach, or Elephant Tree. <The Hesperian, IV, No. 2, pp. 49–51, with plate, April.

This article contains the original description of this species by Kellogg with interesting notes on the tree by Veatch.

1861. Gray, Asa. Enumeration of a Collection of Dried Plants Made by L. J. Xantus, at Cape San Lucas, etc., in Lower California, Between August, 1859, and February, 1860, and Communicated to the Smithsonian Institution. <Proc. Amer. Acad. of Arts and Sci., V, pp. 153–173, January.

An important list of 121 species including a number described as new.

1861. Ives, Lieut. Joseph C., and others. Report upon the Exploration of the Colorado River of the West, in 1857 nd 1858. In 5 parts, with maps and plates, quarto. Washington. Senate Doc.

Part I, General Report [Narrative], pp. 131, by Lieut. J. C. Ives.
Part II. Hydrographic Report, pp. 14, by Lieut. J. C. Ives.
Part III. Geological Report, pp. 154, by Dr. J. S. Newberry.
Part IV. Botany, pp. 30, by Gray, Torrey, Thurber, and Engelmann.
Part V. Zoology, pp. 6, by S. F. Baird.

This report contains interesting information concerning the Gulf of California and the Colorado River and adjacent country up to the big bend and thence through northern Arizona to Fort Defiance.

1864. BAEGERT, JACOB. An Account of the Aboriginal Inhabitants of the Californian Peninsula. <Annual Report Smithsonian Institution for 1863, pp. 352–369, 8vo. Washington.

A translation by Dr. Charles Rau from the original of those parts of Baegert's Nachrichten relating to the natural history and native population of the peninsula.

1864. COMBIER, C. Voyage au Golfe de Californie. Nuits de la Zone Torrid, Accompagné d'une Carte de la Sonora. pp. 544, with map, 8vo. Paris.

Narrative of voyages in 1828–1831 to Tampico and along the west coast of Mexico to head of the Gulf of California, with an account of the pearl fisheries in the gulf, and of a journey from Mazatlan across country to Durango and on to Vera Cruz, including a deer hunt at Guaymas and a bear seen in the mountains of Durango. Great numbers of pelicans were noted in the gulf.

1865. LEESE, JACOB P. Historical Outline of Lower California. Pp. 46, 8vo. New York.

This pamphlet was published to exploit a colonization land grant in southern Lower California given the author by the Mexican Government. It contains a brief account of the southern part of the peninsula and various documents relating to the grant.

1866. GILL, THEODORE. Prodrome of a Monograph of the Pinnipedes. <Proc. Essex Inst., V, p. 13, March.

The name and distribution of *Macrorhinus angustirostris* appear in the text and a footnote gives some of its characters, thus constituting the original description of the northern elephant seal.

1866. ————. On a New Species of the Genus *Macrorhinus*. <Proc. Chicago Acad. Sci., I, pp. 33–34, April.

A brief description of *Macrorhinus angustirostris*. Type locality, San Bartholomew Bay, Lower California. This publication is antedated by that in the Essex Institute.

1868. ANONYMOUS. Lower California: Its Geography and Characteristics, with a Sketch of the Grant and Purposes of the Lower California Co. Pp. 1–44, with map, 8vo. New York.

Gives an account of the formation and grant of the Lower California Co., with a list of its officers. Also Taylor's Historical Summary of the peninsula, which again appears in the appendix to Browne's Resources of the Pacific Slope.

1868. BROWNE, J. ROSS. Explorations in Lower California. <Harpers New Monthly Magazine, Vol. 37, pp. 578–591 (October); pp. 740–752 (November); Vol. 38, pp. 9–23 (December).

A good popular account of the southern end of the peninsula from Cape San Lucas and La Paz to Magdalena Bay in 1866, with comments on some of the former colonization schemes. Browne's expedition was in the interest of the Lower California Co. of New York.

1868. TAYLOR, ALEXANDER S. Historical Summary of Lower California. <Appendix to "Lower California: Its Geography and Characteristics." Pp. 24–40, 8vo. New York.

1869. SCAMMON, CHARLES M. [and EDWARD D. COPE]. On the Cetaceans of the Western Coast of North America. <Proc. Acad. Nat. Sci., Philadelphia, XXI, pp. 13–63, April.

This paper is in two parts: Part I, by Cope, contains a systematic synopsis of the species. Part II, by Scammon, on habits and distribution, includes an account of the sea elephant.

1870. HARTE, FR. BRET. The Story of an Ornithologist. <Overland Monthly, IV, pp. 168–173, February.

A good biographical notice of A. J. Grayson.

1870. SCAMMON, Capt. C. M. Sea Otters. <Overland Monthly, IV, pp. 25–30, January.

A popular account of sea otters and their hunting from Lower California to the Aleutian Islands, with some notes on the habits of the Lower Californian animal.

1870. ————. Sea-Elephant Hunting. <Overland Monthly, IV, pp. 112–117, February.

A popular account of the northern and southern sea elephants, with notes on the northern species along the coast of Lower California.

1870. ————. On the Lower California Coast. <Overland Monthly, IV, pp. 230–238, March.

Contains interesting notes on whaling in Magdalena Bay and elsewhere on the coast of the peninsula.

1871. ANONYMOUS. Nulidad del Contrato Leese. Folio, 23 pp. Mexico.

Nullification of the contract made in 1864 with Jacob P. Leese for the colonization of lands around Magdalena Bay in Lower California. Name, age, etc., of each colonist is given. (Not seen.)

1871. DEKAY, DRAKE. In Relation to Occurrences at Magdalena Bay, Lower California, Mexico. Pp. 90, 8vo. San Francisco.

A report by the United States consul at Magdalena Bay, with accompanying documents concerning the capture of the town and mistreatment of American employees and colonists of the Lower California Co. in October, 1871, by insurgents from La Paz.

1872. HERNANDEZ, El General JOSÉ MARIA PEREZ. Compendio de la Geographia del Territorio de la Baja California. 12mo., pp. 1–95. Mexico.

A brief school geography of the peninsula, with an account of the local government.

1873. EVANS, TALIESAN. South of the Boundary Line. <Overland Monthly, XI, pp. 157–162, August.

This is mainly an account of mining activity in the northern part of the peninsula, with notes on the country and people.

1874. PALOU, PADRE FR. FRANCISCO. Noticias de la Nueva California. 4 vols, pp. 270, 301, 315, 253, large 8vo, with plates. San Francisco.

A compilation of Spanish missionary activities and journeys in Lower and Upper California written prior to August, 1784. The parts referring to Lower California contain little of value concerning the country or its inhabitants.

1874. SCAMMON, CHARLES MELVILLE. The Marine Mammals of the Northwestern Coast of North America. Pp. 318, with plates and cuts, quarto. San Francisco and New York.

Contains a general account of the habits of the species, with methods of hunting them, especially along the west coast of Lower California. Many of these notes were previously published in the Proceedings of the Philadelphia Academy of Natural Sciences for 1869, pp. 13–63. These notes contain about all we know concerning the life histories of a number of species of marine mammals in this region.

1876. Palmer, Edward. (*See* Watson.)
Notes on plants of Guadalupe Island.

1876. Ridgway, Robert. Ornithology of Guadalupe Island, Based on Notes and Collections Made by Dr. Edward Palmer. <Bull. U. S. Geol. and Geog. Surv. Terr., II, pp. 183–195.
This was the first collection of birds from the island. Nine species are listed, of which eight are described as new, and some interesting notes on their habits are given.

1876. Watson, Sereno. Botanical Contributions.
1. On the Flora of Guadalupe Island, Lower California, pp. 105–112.
2. List of a Collection of Plants from Guadalupe Island made by Dr. Edward Palmer, with his Notes upon Them, pp. 112–121.
3. Descriptions of New Species of Plants, Chiefly Californian, with Revisions of Certain Genera, pp. 121–148.
<Proc. Amer. Acad. Arts and Sci., XI, 1875, pp. 105–148.
Contains interesting general notes on the climate and physical character of Guadalupe Island and its flora based on the collections and notes made by Dr. Palmer in 1874. The list contains 119 species of plants, including a number of new species, and notes by the collector.

1877. Ridgway, Robert. The Birds of Guadalupe Island, Discussed with Reference to the Present Genesis of Species. <Bull. Nutt. Orn. Club., II, pp. 58–66, July.
A general discussion of the origin and characters of the island forms.

1877. Streets, Thomas H. Contributions to the Natural History of the Hawaiian and Fanning Islands and Lower California. <Bulletin U. S. Nat. Mus., No. 7, Ornithology, pp. 9–33; Herpetology, pp. 35–42.
Contains notes on species of birds and reptiles observed on the coasts and islands of Lower California in 1874–75.

1879. Ferrel, Bartolomé. Voyage of Cabrillo in 1542. <U. S. Geographical Surveys west of the 100th Meridian, Vol. VII, Archaeology, pp. 299–314. Translated from the original by Richard Stuart Evans.
A translation of a diary of Cabrillo's voyage along the west coast of Upper and Lower California.

1882. Parry, C. C. A New North American Rose. <Bull. Torr. Bot. Club., IX, pp. 97–98, August.
Includes original description by Engelmann of this interesting species, which was discovered by Parry, Pringle, Orcutt, and Jones at Todos Santos Bay.

1882. Ridgway, Robert. On Two Recent Additions to the North American Bird Fauna, by L. Belding. <Proc. U. S. Nat. Mus., IV, pp. 414–415, April 25.
First records of the occurrence of *Motacilla ocularis* and *Dendroica vieilloti bryanti* from La Paz. (The latter afterwards described as *D. bryanti castaneiceps*, Ridg.)

1882. ————. Descriptions of Some New North American Birds. <Proc. U. S. Nat. Mus., V, pp. 344–346, September 5.
Contains original descriptions of *Geothlypis beldingi* and *Rallus beldingi*.

1883. Belding, L. [and Robert Ridgway]. Catalogue of a Collection of Birds Made at Various Points Along the Western Coast of Lower California, North of Cape St. Eugenio. <Proc. U. S. Nat. Mus., V, pp. 527–532, March 21. [Edited by Robert Ridgway.]
A briefly annotated list with critical comments on some species by Robert Ridgway.

1883. Belding, L. [and Robert Ridgway]. Catalogue of a Collection of Birds Made Near the Southern Extremity of the Peninsula of Lower California. <Proc. U. S. Nat. Mus., V, pp. 532–549, March 21. [Edited by Robert Ridgway.]
A briefly annotated list with critical notes on some of the species by Robert Ridgway. A footnote contains a list of 34 species collected by Xantus in the cape district, which were not collected by Belding.

1883. Belding, L. Second Catalogue of a Collection of Birds Made Near the Southern Extremity of Lower California. [Edited by R. Ridgway.] <Proc. U. S. Nat. Mus., VI, pp. 344–352, December 27.
A briefly annotated list of species observed between December, 1882, and March 23, 1883, in the cape district, with critical notes by Robert Ridgway.

1883. Ridgway, Robert. Descriptions of Some New Birds from Lower California, Collected by Mr. L. Belding. <Proc. U. S. Nat. Mus., VI, pp. 154–156, October 5.
Original descriptions of *Lophophanes inornatus cineraceus*, *Psaltriparus grindae*, and *Junco bairdi*, all from the cape district.

1883. ————. *Anthus cervinus* (Pallas) in Lower California. <Proc. U. S. Nat. Mus., VI, pp. 156–157, October 5.
Records a specimen collected by Belding at San Jose del Cabo, January 26, 1883.

1883. ————. Note on *Merula confinis* (Baird). <Proc. U. S. Nat. Mus., VI, pp. 158–159, October 5.
Records the collections of the first specimen subsequent to the type, by Belding in the Laguna Mountains, February, 1883.

1884. Gray, Asa. *Veatchia* Nov. Gen. *Anacardiacearum*. <Bull. Calif. Acad. Sci., I, pp. 4–5, February.
Description of *Veatchia cedrosensis* [= *Pachycormus discolor*].

1884. Kellogg, A. New Species of Cedros Island Plants. <Bull. Calif. Acad. Sci., I, pp. 6–7, February.
Descriptions of two new species collected by Dr. J. A. Veatch.

1884. Ten Kate, H. Matériaux pour servir à l'Anthropologie de la presqu' Isle Californienne. <Bull. de la Soc. d'Anthropologie, separately paged 1–23, with cuts, July, Paris.
A brief paper on the Indians once occupying southern Lower California, with cuts and notes on skulls collected by the author in 1883 on Espiritu Santo Island and elsewhere in that region.

1885. Belding, L. The Piricue Indians. <The West American Scientist, I, No. 4, pp. 21–22, March.
Notes on the Indians of the cape district and their method of burial. These notes refer to the same skulls described by Ten Kate in paper mentioned above.

1885. Greene, Edward Lee. Studies in the Botany of California and Parts Adjacent, II.
1. Three New Genera, pp. 179–182.
2. Miscellaneous Species, mostly new, pp. 182–214.
3. Notes on Guadalupe Island, pp. 214–220.
4. A Calalogue of the Flowering Plants and Ferns of Guadalupe Island, pp. 220–228. <Bull. Calif. Acad. Sci., I, No. 4, pp. 179–228, August.
Includes notes and descriptions of new species from the coast and islands of Lower California.

1885. Greene, Edward L. Botany of the Coronados Islands. <The West American Scientist, I, No. 10, pp. 69–71, October.
A list of nearly 70 species, one of which (*Malacothrix insularis*) is mentioned as new.

1885. Parry, C. C. New Genus of Euphorbiaceae from Lower California. <The West American Scientist, I, pp. 13–15, February.
Original description of the genus *Tetracoccus*.

1885. Ramos, Joaquin M. Trabajos Ejecutados por la Comision exploradora de la Baja California, el año de 1884. Anales del Ministerio de Fomento, 8vo, Mexico, 1885.
Mainly a report on placer and other mines but with general information about topography, towns, etc.

1885. Ridgway, Robert. A Review of the American "Golden Warblers." <Proc. U. S. Nat. Mus., VI, pp. 348–350, September 2.
Contains original description of *Dendroica bryanti castaneiceps* Ridgway, from La Paz, Lower California.

1886. Bryant, Walter E. Cerros Island. <Forest and Stream, XXVII, No. 4, pp. 62–64, August 19.
Contains a general account of the island with an annotated list of 27 species of birds noted there from January 7 to 11, 1885. A deer and a rabbit were also noted.

1886. Orcutt, C. R. Northern Lower California. <West American Scientist, II, pp. 37–41, June.
A general description of the country along the route from San Diego to El Rosario.

1886. ————. New Lower Californian Cactuses. <The West American Scientist, II, No. 16, p. 46, with plate, June.
Original descriptions of *Echinocactus orcuttii* and *Cereus phoeniceus pacificus* from northern part of the peninsula.

1886. ————. A Botanical Trip. <West American Scientist, II, pp. 53–58, July.
Contains interesting notes on a number of plants met with on a journey from San Diego, Calif., to near San Fernando, Lower California, in spring of 1886.

1886. Ramos, Joaquin M. Informe relativo a los Trabajos Ejecutados por la Comision Exploradora de la Baja California, en el Año de 1884 Presentado a la Secretaria de Fomento, Mexico. 8vo, pp. 224, with maps and cuts.
Contains general information concerning the middle of the peninsula from Mulege to Ojo de Liebre, with notes on geology and physiography; also account of the Calmalli placers, El Boleo copper mine at Santa Rosalia, the pearl fishery, and the orchilla industry.

1886. Townsend, Charles H. An Account of Recent Captures of the California Sea Elephant, and Statistics Relating to the Present Abundance of the Species. <Proc. U. S. Nat. Mus., VIII, pp. 90–93, 1885.
An account of a trip along the coast of Lower California, October to December, 1884, when specimens were secured at San Cristobal Bay, with some historical notes.

1886. Vasey, George. A New Genus of Grasses. <The West American Scientist, III, No. 20, pp. 4–6, December.
Description of *Orcuttia californica*—new genus and species from near San Quintin, Lower California.

1887. Anonymous. A Beautiful Peninsula: The Government and People of Lower California, etc. <Sketch of the settlement and exploration of Lower California [in supplementary appendix to Resources of the Pacific Slope by J. Ross Browne], pp. 174–177, New York.
An unsigned letter dated La Paz, December 22, 1867, giving information concerning local conditions, government, products, and colonization companies.

1887. . . . Lower California, the Peninsula. 8vo folder of 24 unnumbered pages. New York City.
This is a publicity folder of the International Co. of Mexico in which the lands held by the company are described in glowing terms to attract colonists. These efforts to colonize failed completely.

1887. Belding, L. Collecting in the Cape Region of Lower California. <The West American Scientist, III, No. 24, pp. 93–97, April.
General notes on the region and a naturalist's experiences there from 1881–83.

1887. ————. Reptiles of the Cape Region of Lower California. <The West American Scientist, III, pp. 97–99, April.
A briefly annotated list of 54 species.

1887. Browne, J. Ross. Resources of the Pacific Slope. A statistical and descriptive summary of the mines and minerals, climate, topography, agriculture, commerce, manufactures, and miscellaneous productions of the States and Territories west of the Rocky Mountains with a sketch of the settlement and exploration of Lower California. Pp. 1–678; 1–200, 8vo. New York.
The last 200 pages of this volume contain papers on Lower California by several authors, which are cited elsewhere in this list.

1887. Bryant, Walter E. Additions to the Ornithology of Guadalupe Island. <Bull. Calif. Acad. Sci., II, pp. 269–318, January.

An annotated list o f35 species observed by the author during parts of 1885–86 ,with notes on the physical character and climate of the island.

1887. ————. Description of a New Subspecies of Petrel from Guadalupe Island. <Bull. Calif. Acad. Sci., II, p. 450, July.

Original description of *Oceanodroma leucorhoa macrodactyla*.

1887. Gabb, William M. Exploration of Lower California. <A sketch of the settlement and exploration of Lower California [in supplementary appendix to Resources of the Pacific Slope, by J. Ross Browne], pp. 82–122, New York.

An account of an expedition overland from Cape San Lucas to San Diego, Calif., in 1867, with notes on the country and its resources.

1887. Hawks, J. D. Journal of the Expedition of Mr. J. D. Hawks and Party Through the Interior of the Peninsula of Lower California, from San Domingo to San Diego. <A sketch of the settlement and exploration of Lower California [in supplementary appendix to Resources of the Pacific Slope, by J. Ross Browne], pp. 132–142, New York.

This is a briefitinerary of a trip made between August and October, 1849, by J. D. Hawks, Daniel T. Hulett, George H. Davis, John C. Gilsey, Henry M. Smith, and J. J. Ellis.

1887. Lopatecki, Maurice. Lower California Notes. Reprint from San Diegan of May 14. <The West American Scientist, III, pp. 129–130, May.

Notes on the flora and topography of the west coast of the peninsula south of Santa Rosalia Bay. The English company located in San Andres Valley is mentioned here.

1887. Orcutt, C. R. A Lemonade and Sugar Tree. <The West American Scientist, III, pp. 45–47, February.

Notes on sugar producing species of *Rhus* in Lower California.

1887. ————. The Oaks of Southern and Lower California. <The West American Scientist, III, pp. 135–139, with photograph, May.

Includes brief notes on the species of San Diego County and northern Lower California.

1887. ————. Notes on Lower California Plants. <The West American Scientist, III, pp. 139–140, May.

Contains a brief list of species with Mexican names collected in San Andres Valley and near Santa Rosalia Bay by Maurice Lopatecki during the survey of the west coast of the peninsula by the U. S. S. *Ranger*.

1887. Ortega, José. Historia del Nayarit, Sonora, Sinaloa y Ambas Californias. Pp. I–IX, 564, 8vo, new ed. Mexico (first ed. Barcelona, 1854).

An account of missionary work during the early Spanish occupation, including trips of Kino to northern Sonora and mouth of the Colorado, and of Consag north from Mulege along the gulf coast.

1887. Randall, A. G. Extracts from a History of Old or Lower California. <A sketch of the settlement and exploration of Lower California [in supplementary appendix to Resources of the Pacific Slope by J. Ross Browne], pp. 155–172, New York.

This is a translation of parts of Clavijero's work cited elsewhere.

1887. Ridgway, Robert. Description of Two New Races of *Pyrrhuloxia sinuata* Bonap. <Auk, IV, p. 347, October.

Original description of *P. s. peninsulæ*.

1887. Scammon, Capt. C. M. Report of Capt. C. M. Scammon, of the United States Revenue Service, on the West Coast of Lower California. <A sketch of the settlement and exploration of Lower California [in supplementary appendix to Resources of the Pacific Slope, by J. Ross Browne], pp. 123–131, New York.

An account of the coast and islands on the west side of the peninsula previous to 1867, with notes on the former whaling and sealing industries.

1887. Secretario de Fomento. Exposicion que hace el Secretario de Fomento sobre la Colonizacion de la Baja California. Pp. 113, 8vo. Mexico.

An official report by the Secretary of the Interior of Mexico concerning grants for colonization purposes to Adolfo Bulle, G. Luis Müller, and others in Lower California and elsewhere in Mexico, in reply to criticism concerning these acts.

1887. Taylor, Alexander S. Historical Summary of Lower California, from Its Discovery in 1832 to 1867. <A sketch of the settlement and exploration of Lower California [in a supplementary appendix to Resources of the Pacific Slope, by J. Ross Browne], pp. 6–77, New York.

The history and resources of the peninsula are here compiled and to much of value considerable misinformation is added.

1887. Veatch, John A. Report of Dr. John A. Veatch on Cerros or Cedros Island. <A sketch of the settlement and exploration of Lower California [in supplementary appendix to Resources of the Pacific Slope, by J. Ross Browne], pp. 143–154, New York.

Contains a general description of the island with interesting notes on its natural history from observations made during a visit extending from June to August, 1859.

1888. Brewster, William. Descriptions of Supposed New Birds from Lower California, Sonora and Chihuahua, Mexico, and the Bahamas. <Auk, V, pp. 82–95, January.

Ardea virescens frazari, *Haematopus frazari*, *Columba fasciata vioscæ*, and *Megascops aspersus* are described from southern Lower California.

1888. Brewster, William. On Three Apparently New Subspecies of Mexican Birds. <Auk, V, p. 136, April.
Original description of *Glaucidium gnoma hoskinsi* from the cape district.

1888. Bryant, Walter E. Description of a New Subspecies of Song Sparrow from Lower California, Mexico. <Proc. Calif. Acad. Sci., 2d ser., I, pp. 197–200, September.
Describes *Melospiza fasciata rivularis* from Comondu.

1888. Curran, Mary K. Botanical Notes. I. Plants from Baja California. <Proc. Calif. Acad. Sci., 2 ser., I, pp. 227–237, December 11.
A list of about 100 species collected by Walter E. Bryant in the vicinity of Magdalena Bay early in 1888, accompanied by critical notes.

1888. Greene, Edward Lee. The Botany of Cedros Island. <Pittonia, I, pp. 194–200, June.
General notes on the botany of the island made during a three days' visit the latter part of April, 1885.

1888. ————. A List of the Known Species of Cedros Island Plants. <Pittonia, I, pp. 200–208, June.
An annotated list of 82 species.

1888. Lindgren, W. Notes on the Geology of Baja California, Mexico. <Proc. Calif. Acad. Sci., 2d ser., I, pp. 173–196, with map and diagram, September 25.
Contains some interesting notes on the topography and formation of the northern end of the peninsula.

1888. Nordhoff, Charles. Peninsular California. Pp. 130, with plates and maps, 8vo. New York.
Gives a general account of Lower California, especially the northern part, mainly in the interest of a colonization company. Much erroneous matter is given concerning resources and agricultural possibilities. One of the colonizing officials is quoted to the effect that there are "hundreds of moose" in the mountains.

1888. Orcutt, C. R. The Gold Fields of Lower California. <The West American Scientist, V, pp. 4–5, October.
A notice of mining activity brought about by the discovery of the Santa Clara Placers.

1889. Anthony, Alfred W. New Birds from Lower California, Mexico. <Proc. Calif. Acad. Sci., 2d ser., II, pp. 73–82, October 11.
Describes new birds taken during a visit to the San Pedro Martir Mountains the spring of 1889, with notes on distribution and habits.

1889. Anthony, A. W. [edited by Walter E. Bryant]. General Ornithological Notes. I. Nesting Habits of the California Brown Pelican (*Pelecanus californicus*). <Proc. Calif. Acad. Sci., 2d ser., II, pp. 83–85, October 11.
From observations made on the islands along the western coast of Lower California.

1889. ————. Occurrence of *Phæthon æthereus* and Capture of *Scolecophagus carolinus* in Lower California. <Proc. Calif. Acad. Sci., 2d ser., II, p. 86.

1889. Bancroft, H. H. History of the Pacific States of North America. XI, pp. I–VI, pp. 1–814, 8vo. San Francisco.
Chapters 29 and 30 contain a brief history of Lower California from 1800 to 1888, including Walker's filibustering expedition and the projects of numerous colonization companies.

1889. Belding, L. The Deer of Southern Lower California. <The West American Scientist, VI, No. 43, pp. 26–27, May.
Remarks on the large size of the deer of the region; estimates that one shot by him weighed 250 pounds and that they sometimes exceed 300 pounds in weight. Calls attention to the erroneous idea of the size of the cape deer by the statement by Caton in his Antelope and Deer of America, pp. 119 and 337 (2d edition).

1889. Brandegee, Townshend S. A Collection of Plants from Baja California, 1889. <Proc. Calif. Acad. Sci., 2d ser., II, pp. 117–215, November.
Contains an annotated list of over 700 species of plants collected about Magdalena Bay and thence on an overland trip to San Quintin. The introductory remarks contain interesting general information and descriptions of new species. An important paper on the flora of the peninsula.

1889. Brewster, William. Descriptions of Supposed New Birds from Western North America and Mexico. <Auk, VI, pp. 85–98, April.
Original descriptions of *Empidonax griseus* and *Progne subis hesperia* from Lower California.

1889. Bryant, Walter E. Descriptions of the Nests and Eggs of Some Lower California Birds with a Description of the Young Plumages of *Geothlypis beldingi*. <Proc. Calif. Acad. Sci., 2d ser., II, pp. 20–24.
Notes from the southern part of the peninsula.

1889. ————. Provisional Descriptions of Supposed New Mammals from California and Lower California. <Proc. Calif. Acad. Sci., 2d ser., II, pp. 25–27, June 20.
Original description of *Spermophilus grammurus atricapillus* from Comondu.

1889. ————. A Catalogue of the Birds of Lower California, Mexico. <Proc. Calif. Acad. Sci., 2d series, II, pp. 237–320, with maps, December.
A list of 320 species and subspecies annotated with the observations of the author and others to date, with notes on the work done and places visited and a short bibliography.

1889. Greene, Edward Lee. The Vegetation of the San Benito Islands. <Pittonia, I, pp. 261–262, March.
General remarks on the islands and their flora.

1889. ————. A List of San Benito Plants. <Pittonia, I, pp. 263–266, March.
Twenty-four species collected by Lieut. Charles F. Pond are enumerated, of which three are described as new.

1889. GREENE, EDWARD LEE. A Supplementary List of Cedros Island Plants. <Pittonia, I, pp. 266–269, March.
Based on a small collection of plants made by Lieut. Charles F. Pond during the winter of 1888–89. Several species are described as new.

1889. ————. Some Plants from the Bay of San Bartolome, Lower California. <Pittonia, I, pp. 287–292, April.
Twenty-four species are enumerated, including a number described as new, all from a collection made by Lieut. Charles F. Pond, in March, 1889.

1889. HARKNESS. H. W. Fungi Collected by T. S. Brandegee in Lower California in 1889. <Proc. Calif. Acad. Sci., 2d ser., II, pp. 231–232, December 20.
A list of species collected on an overland journey from Magdalena Bay to San Quintin, and original description of *Puccinia ornata*.

1889. LINDGREN, W. Petrographical Notes from Baja California, Mexico. <Proc. Calif. Acad. Sci., 2d ser., II, pp. 1–17, June.
These notes are based mainly on rocks from the northwestern part of the peninsula.

1889. MILLSPAUGH, C. F. Contributions to North American Euphorbiaceæ. I. Upon a Collection of Euphorbiaceous Plants, made by Mr. T. S. Brandegee, in 1889, on the Mainland of Lower California and the Adjacent Islands of Magdalena and Santa Margarita. <Proc. Calif. Acad. Sci., 2d ser., II, pp. 217–230, December 17.
With notes and descriptions of new species.

1889. ORCUTT, C. R. A New Species of Cereus. <The West American Scientist, VI, p. 29, May.
Description of *Cereus cochal* from Todos Santos Bay to San Fernando.

1889. ————. Flora of the Alamo. <The West American Scientist, VI, pp. 132–134, October.
Botanical notes, written on a horseback trip in the vicinity of Alamo, Lower California.

1889. PARRY, C. C. A New Species of Eriogonum (*E. fastigiatum*), from Lower California. <The West American Scientist, VI, pp. 102–103, September.

1889. VASEY, GEORGE, and JOSEPH N. ROSE. List of Plants Collected by Dr. Edward Palmer in Lower California in 1889. <Proc. U. S. Nat. Mus., XI, pp. 527–536, September.
Annotated lists of plants collected at San Quintin and Lagoon Head, Lower California.

1889. SANCHEZ, FACIO M. The Truth About Lower California. Pp. 94, with maps, 8vo. San Francisco.
A report with numerous documents concerning colonization in the peninsula, especially concerning difficulties of the Mexican International Co. of Colonization and its colonies at Ensenada and San Quintin shortly before this report.

1889. WATSON, SERENO. Contributions to American Botany. I. Upon a Collection of Plants made by Dr. E. Palmer, in 1887, about Guaymas, Mexico, at Muleje and Los Angeles Bay in Lower California, and on the Island of San Pedro Martin [Martir] in the Gulf of California. <Proc. Amer. Acad. Arts and Sci., XXIV, pp. 36–82.
An important list, including many new species from Lower California. Of the 415 species contained in the collection from both sides of the Gulf of California, 89, or more than one-fifth, are recorded as new.

1890. ANTHONY, A. W. The Nests and Eggs of Townsend's Junco (*Junco townsendi*) and San Pedro Partridge (*Oreortyx pictus confinis*). <Zoe, I, pp. 5–6, March.
The first account of the nesting of these birds in the San Pedro Martir Mountains.

1890. . . . Illustrated History of Southern California. Quarto, pp. 898, with portraits. Chicago.
Gives a brief historical account of Lower California, but the volume is devoted mainly to short biographies of residents of southern California, which appears to have been the object of this publication.

1890. BRANDEGEE, T. S. An Arborescent Polygala. <Zoe, I, pp. 4–5, March.
Notes on the tree species of Lower California (*Polygala apopetala*).

1890. ————. A Cardon Forest. <Zoe, I, p. 26, March.
Contains notes on the distribution of the giant cactuses in Lower California.

1890. ————. The Effect of Rain on Fouquieria. <Zoe, I, pp. 40–41, April.
Describes the sudden appearance of leaves after the infrequent rains in Lower California.

1890. ————. A New Perityle. <Zoe, I, p. 54, April.
Description of *Perityle cuneata*, from Sierra de la Laguna, near Todos Santos, Lower California.

1890. ————. The Hedgerows of Todos Santos. <Zoe, I, pp. 179–181, August.
Contains interesting general notes on the appearance and distribution of various species of trees and shrubs in southern Lower California.

1890. ————. Notes Concerning the Collection of Plants Made by Xantus at Cape St. Lucas and Vicinity. <Zoe, I, pp. 269–272, November.
Contains notes on the cape district, its climate, and a number of little-known species of plants.

1890. ————. A New Cottonwood from Baja California. <Zoe, I, pp. 274–275, November.
Original description of *Populus monticola*, a striking species known only from the Sierra de la Laguna.

1890. ————. A New Nolina. <Zoe, I, pp. 305–306, December.
Original description of *Nolina beldingi*, an arborescent species peculiar to the upper slopes of the Sierra de la Laguna.

1890. ————. Studies in Coreopsideæ and Tagetineæ, Especially of Lower California, with Descriptions of Some New Species. <Zoe, I, pp. 308–314, December.

1890 BREWSTER, WILLIAM. A New Subspecies of the Solitary Sandpiper. <Auk. VII, pp. 377–379, October, 1890.
Original description of *Totanus solitarius cinnamomeus* from San Jose del Cabo.

1890. Bryant, Walter E. Notices of Supposed New Birds. <Zoe, I, pp. 148–150, July.
Contains notes on status of *Otocoris alpestris pallida* and proposes *Auriparus flaviceps ornatus* as a new name for the verdin of Lower California, southern California, and southwestern Arizona.

1890. ————. El Zorillo. <Zoe, I, pp. 272–274, November.
An account of skunks (*Spilogale lucasana*) causing hydrophobia in the cape region.

1890. Cogniaux, A. Cucurbitacearum Novum Genus Et Species. <Proc. Calif. Acad. Sci., 2d ser., III, pp. 58–60, July 9.
The new genus *Brandegea*, and a new species *Echinocystis brandegei*, described from Lower California.

1890. Eaton, D. C. A New Fern from Lower California. <Zoe, I, p. 197, September.
Asplenium blepharodes described from the Sierra de la Laguna.

1890. Ellicott, John M. Should We Possess Lower California? <Overland Monthly, 2d ser., XVI, pp. 473–476, November.
Discusses adversely the value of Lower California to the United States.

1890. Lindgren, Waldemar. Notes on the Geology and Petrography of Baja California, Mexico. <Proc. Calif. Acad. Sci., 2d ser., III, pp. 25–33, April.
Notes on the rocks collected by Bryant in the southern part of the peninsula, and comments on the geology of that area.

1890. Merriam, C. Hart. Contribution toward a Revision of the Little Striped Skunks of the Genus Spilogale. <North American Fauna No. 4, October 8, pp. 1–16, Pl. I.
Contains original description of *Spilogale lucasana* from Cape St. Lucas.

1890. Orcutt, C. R. Some Notes on Echinocactus. <Garden and Forest, III, p. 238, May 14. Reprinted in West American Scientist, VII, pp. 67–70, December.
A brief discussion of the species occurring in southern California and Lower California.

1890. Palmer, Edward. (*See* Vasey, George, and Joseph Nelson Rose, for field notes by Palmer.)

1890. Townsend, Chas. H. Birds from the Coasts of Western North America and adjacent Islands, Collected in 1888–89, with Descriptions of New Species. <Proc. U. S. Nat. Mus. XIII, pp. 136–138, September.
Contains brief annotated lists from the coast of the peninsula and adjacent islands, including Guadalupe, and the original description of *Amphispiza belli cinerea* from Ballenas Bay.

1890. ————. Reptiles from Clarion and Socorro Islands and the Gulf of California. <Proc. U. S. Nat. Mus., XIII, pp. 134–144, September.
Includes a few species from the gulf coast of the peninsula and from Carmen and Angel de la Guardia Islands.

1890. Vasey, George, and Joseph Nelson Rose. List of Plants Collected by Dr. Edward Palmer in Lower California in 1889. <Contr. Nat. Herb., I, pp. 9–28, July 18.
Annotated list of collections made at Lagoon Head, Cedros Island, San Benito Island, Guadalupe Island, Lower California, and at Colonia, Lerdo, Sonora, near the head of the Gulf of California. A number of species are described as new.

1890. Vasey, George, and J. N. Rose. List of Plants Collected by Dr. Edward Palmer in Lower California and western Mexico in 1890. <Contr. Nat. Herb., Vol. I, No. 3, pp. 63–92, November.
Collections were made at La Paz, San Pedro Martir and Raza Islands, Santa Rosalia, and Santa Agueda, Lower California. The list includes notes and descriptions of a new genus and many new species.

1891. anthony, A. W. Secondary Migration of Birds. <Zoe, I, pp. 379–381, February.
Includes notes on the migration of *Harporhynchus cinereus* [= *Toxostoma cinerea mearnsi*] at San Quintin, Lower California.

1891. Brandegee, T. S. A New Species of Esenbeckia (with plate). <Zoe, I, p. 378, February.
Describes *Esenbeckia flava* from San Jose del Cabo.

1891. ———— The Plants Pecular to Magdalena and Santa Margarita Islands. <Zoe, II, pp. 11–12, April.
Contains notes on the physiography of the islands and the following species are given as peculiar to them; *Gongylocarpus fruticulosus*, *Mamillaria halei*, *Agave margaritae*, *Brickellia hastata*, and *Viguiera subincisa*.

1891. ————. Cactaceae of the cape region of Baja California. <Zoe, II, pp. 18–22, April.
Includes notes on the distribution of 12 species, and original descriptions of the following: *Mamillaria roseana*, *Cereus striatus*, and *Opuntia rotundifolia*.

1891. ————. Drymaria in Baja California. <Zoe, II, pp. 68–70, April.
Eight species are listed, including two described as new.

1891. ————. Field Notes on the Plants of Baja California. <Zoe, II, pp. 145–152, July.
Contains interesting notes on the distribution, habits, and economic uses of a number of species in the southern part of the peninsula.

1891. ————. Flora of the Cape Region of Baja California. <Proc. Calif. Acad. Sci., 2d ser., III, pp. 108–182, July and August.
A brief description of the cape region and a list of the plants known to occur from La Paz and Todos Santos southward based upon two collections made in that part of the peninsula in 1890. Nearly 700 species are enumerated, including some collected by Dr. Palmer at La Paz and by Xantus at Cape San Lucas, that were not found by Brandegee. Many new species are described and others are accompanied by field or critical notes. One of the most important papers yet published on plants of this region.

1891. Brewster, William. Descriptions of Seven Supposed New North American Birds. <Auk, VIII, pp. 139–149, April.
Original descriptions of *Contopus richardsoni peninsulæ*, *Pipilo maculatus magnirostris*, *Vireo solitarius lucasanus*, and *Sitta carolinensis lagunæ*, from the cape region of Lower California.

1891. Bryant, Walter E. Andrew Jackson Grayson. <Zoe, II, pp. 34–68, April.
A good biographical sketch of Grayson, including his work in Mexico and notes on the life histories of some species of Mexican birds from his manuscript.

1891. ————. Preliminary Description of a New Subspecies of the Genus *Lepus*, from Mexico. <Proc. Calif. Acad. Sci., 2d ser., III, p. 92, April 23.
Original description of *Lepus insularis* from Todos Santos Island.

1891. ————. The Cape Region of Baja California. <Zoe, II, pp. 185–201, October.
A discursive account in which the cape region is defined as that part of the peninsula southward from the base of the mountains between La Paz on the gulf shore and Todos Santos on the Pacific coast; contains author's itinerary and interesting notes on the country and the birds, mammals, and plants; also includes an account of the discovery of *Lepus insularis*, the black jack rabbit of Espiritu Santo Island.

1891. Hemphill, Henry. Edible Mollusks of Western North America. <Zoe, II, pp. 134–139, July.
Includes species living along the coast of Lower California.

1891. Keeler, Charles A. Notes on the Colors of West Coast Mammals. <Zoe, II, pp. 203–216, October.
Contains notes on the Lower California ground squirrel and the black jack rabbit (*Lepus insularis*). The notes regarding the resemblance of the latter to its surroundings are entirely erroneous.

1891. Millspaugh, C. F. Euphorbiaceæ Collected by T. S. Brandegee, Principally in the Vicinity of Todos Santos, Baja California, January and February, 1890. <Zoe, I, pp. 346–348, January.
Sixteen species listed, two described as new.

1891. Orcutt, C. R. A Visit to Lake Maquata. <The West American Scientist, VII, pp. 158–164, May.
Includes a few general and botanical notes on the region about this lake along the western base of the Cocopah Mountains.

1891. ————. *Rosa minutifolia*. <The West American Scientist, VII, pp. 181–182, May.
Notes on the discovery, distribution, and habits of this species.

1891. ————. The Guadalupe Palm. <The West American Scientist, VII, p. 182, May.
Notes on *Erythea edulis* of Guadalupe Island, reprinted from Vick's Magazine, XIV, p. 168.

1891. Townsend, Charles H. Report upon the Pearl Fishery of the Gulf of California. <Bull. U. S. Fish Commission, IX, pp. 91–94, 3 illustrations (1889).
A brief report based on the operations of the Pearl Shell Co. of Lower California along the southern shores of the peninsula and western Mexico to the border of Guatemala.

1892. Bendire, Charles. Life Histories of North American Birds with Special Reference to their Breeding Habits and Eggs. [Part 1.] Smithsonian Contributions to Knowledge, XXVIII[Special Bull. U. S. Nat. Mus. No. 1] pp. x, xii; 446; with 12 colored plates, quarto. Washington.
Contains the life histories of several Lower Californian birds with some original data.

1892. Brandegee, T. S. The Distribution of the Flora of the Cape Region of Baja California. <Zoe, III, pp. 223–231, October.
An important paper including a comparative table based on 732 species showing in condensed form the distribution of the flowering plants and ferns and their relation to the floras of neighboring regions, especially that of the Mexican mainland.

1892. ————. A New *Rumfordia* from Lower California. <Zoe, III, pp. 241–242, with plate, October.
Description of *Rumfordia connata*.

1892. ————. Additions to the Flora of the Cape Region of Baja California. <Proc. Calif. Acad. Sci., 2d ser., III, pp. 218–227, November 10.
The additional species, some of them described for the first time, bring the total number listed for this region up to 739.

1892. Cooper, J. G. Catalogue of the Land and Fresh Water Mollusca of Lower California. Zoe, III, pp. 12–25, April.
Gives notes on the distribution of 45 species.

1892–95. ————. On Land and Fresh Water Shells of Lower California. <Proc. Calif. Acad. Sci., 2d ser., III, pp. 99–103 (Apr. 23, 1892); 207–217 (Oct. 6, 1892); 338–344 (May 5, 1893); 2d ser., IV, pp. 130–143, with plates (Apr. 28, 1894); 2d ser., V, pp. 163–165 (Jan. 8, 1895).
Contains general notes on the country with lists of species, descriptions, and annotations, including altitudes by Eisen.

1892. Merriam, C. Hart. The Geographic Distribution of Life in North America, with Special Reference to the Mammalia. <Proc. Biol. Soc., Washington, VII, pp. 1–64, April.
A historical résumé of the life areas proposed by various authors and discussion and definition of the life zones of North America including northern Mexico and Lower California.

1892. Rose, Joseph Nelson. List of Plants Collected by Dr. Edward Palmer in 1890 on Carmen Island. <Contr. Nat. Herb., I, No. 5, pp. 129–134, June 30.
An annotated list of 68 species, including several new ones, most of which are known from the adjacent peninsula.

1892. Townsend, Charles Haskins. The Pearl Divers of the California Gulf. <The Californian Magazine, II, pp. 116–125, with 7 illustrations, June.
A popular account of the pearl fisheries in the Gulf of California.

1893. Allen, J. A. The Geographical Origin and Distribution of North American Birds Considered in Relation to Faunal Areas of North America. <Auk, X, pp. 97–150, April.
Contains some discussion of the faunal relationships of Lower California and applies the term Saint Lucas Fauna to the life of the area south of La Paz.

1893. ALLEN, J. A. On a Collection of Mammals from the San Pedro Martir Region of Lower California with Notes on Other Species, Particularly of the Genus *Sitomys*. <Bull. Amer. Mus. Nat. Hist., V, pp. 181–202, August 18.
An annotated list with descriptions of four new species and subspecies collected by E. C. Thurber and A. W. Anthony.

1893. ANTHONY, A. W. Birds of San Pedro Martir, Lower California. <Zoe, IV, pp. 228–247, October.
Notes on the physiography of the region and an annotated list of 121 species and subspecies of birds.

1893. BRANDEGEE, T. S. Southern Extension of California Flora. <Zoe, IV, pp. 199–210, October.
General notes on the physiography of Lower California and its floral areas and relationships, with an annotated list of species collected on a trip from San Diego to the San Pedro Martir Mountains, in May, 1893.

1893. T. S. B.[RANDEGEE]. *Perityle rotundifolia* (Benth.). <Zoe, IV, p. 210, October.
A brief note on this species and the genus *Amauria* from San Quintin.

1893. BRYANT, WALTER E. A Rookery of Man-of-war Birds. <Nidiologist, I, pp. 1–3, September.
An account of the colony nesting in the mangroves on the east side of Santa Margarita Island.

1893. EATON, D. C. A New Station for *Asplenium septentrionale*. <Zoe, IV, p. 185, July.
Recorded from the San Pedro Martir Mountains.

1893. ECKFELDT, J. W. List of Lichens from California and Mexico, Collected by Dr. Edward Palmer from 1888 to 1892. <Contr. Nat. Herb., I, No. 8, pp. 291–292, October.
Includes several species from Lower California.

1893. G. E. [=GUSTAV EISEN]. The Investigations of the Collections of the Expedition to Baja California. <Zoe, III, pp. 373–375, January.
A brief notice of recent collections made in Lower California for the California Academy of Sciences and the plans for publishing on them.

1893. FRANCESCHI, F. *Erythea edulis* at Home. <The Gardener's Chronicle (London), 3d ser., XIII, pp. 507–508, April 29.
An interesting account of this palm and its surroundings on Guadalupe Island. Observations made in January, 1893.

1893. ————. Notes on the Flora of Guadalupe Island. <Zoe, IV, pp. 130–139, July.
Some interesting notes on the physiography of the island, with an annotated list of 60 species of plants collected by the author in December, 1892, and January, 1893.

1893. MERRIAM, C. HART. Description of a New Kangaroo Rat from Lower California (*Dipodomys merriami melanurus* subsp. nov.) Collected by Walter E. Bryant. <Proc. Calif. Acad. Sci., 2d ser., III, pp. 345–346, January 5.
Type from San Jose del Cabo.

1893. ————. The Faunal Position of Lower California. Auk, X, pp. 305–307, July.
Criticism of terms used by Dr. J. A. Allen in his paper in the Auk, 1893, pp. 97–150, with reply by Dr. Allen.

1893. MERRILL, GEO. P. The Onyx Marbles: Their Origin, Composition, and Uses, Both Ancient and Modern. Ann. Rept. U. S. Nat. Mus., pp. 541–585, pls. 1–18.
Contains a detailed account (pp. 572–574, pls. 16–18) of the stone belonging to this class at the Tule Arroyo,some 150 miles south of San Diego.

1894. ANTHONY, A. W. Notes on the Genus *Heleodytes*, with a Description of a New Subspecies. <Auk, XI, pp. 210–214, July.
Contains critical remarks on *Heleodytes affinis* and original description of *H. brunneicapillus bryanti*.

1894. BRANDEGEE, T. S. Additions to the Flora of the Cape Region of Baja California, II. <Zoe, IV, pp. 398–408, March.
Contains descriptions of new species and notes on a number of others not previously listed from this region.

1894. BRYANT, WALTER E. Nesting of the Osprey. <The Nidiologist, II, pp. 17–19, with 2 cuts, October.
An account of the nesting of the osprey on Santa Margarita Island.

1894. EMMONS, S. F., and G. P. MERRILL. Geological Sketch of Lower California. <Bull. Geol. Soc. Amer., V, pp. 489–514, pl. 19, April.
A good résumé of the knowledge available on the date of publication with original contributions by the authors from personal observations.

1894. FERNALD, M. L. Notes from the Gray Herbarium. <Zoe, IV, pp. 379–380, February.
Contains original description of *Habenaria lucæcapensis* from the Cape Mountains.

1894. LAMSON-SCRIBNER, F. Lower California Grasses: An Enumeration of the Grasses Collected by Mr. T. S. Brandegee in Lower California in 1892. <Zoe, IV, pp. 385–393, February 26.
An annotated list of 69 species.

1894. MERRIAM, C. HART. Description of Four New Pocket Mice from Lower California. Collected by Walter E. Bryant. Proc. Calif. Acad. Sci., 2d ser., IV, pp. 457–462, September 25.
All from Comondu and southward, and including *Perognathus bryanti*, *P. margaritæ*, *P. spinatus peninsulæ*, and *P. arenarius*.

1894. REEVE, JAMES KNAPP. The Peninsula of Lower California. <Lippincott's Magazine, LIII, pp. 71–78, January,.
A popular account of conditions in the peninsula, especially the northern part, with an optimistic view of the agricultural possibilities not borne out by experience.

1894. Van Denburgh, John. Descriptions of Three New Lizards from California and Lower California, with Notes on *Phrynosoma blainvillii*. <Proc. Calif. Acad. Sci., 2d ser., IV, pp. 296–301, July 12.
Original descriptions of *Uta microscutata* and *Cnemidophorus stejnegeri* from Lower California.

1894. ————. Notes on *Crotalus mitchellii* and "*Crotalus pyrrhus*." <Proc. Calif. Acad. Sci., 2d ser., IV, pp. 450–455, September 25.
Proves that *Crotalus pyrrhus* is a synonym of *C. mitchellii*, with notes on Lower Californian specimens.

1894. ————. *Phrynosoma solaris*, with a Note on Its Distribution. <Proc. Calif. Acad. Sci., 2d ser., IV, p. 456, September 25.
Its known range to Las Animas Bay, Lower California.

1895. Anthony, A. W. A New Subspecies of *Harporhynchus* from Lower California. <Auk, XII, pp. 52–53, January.
Original description of *H. cinereus mearnsi*.

1895. ————. Description of a New *Pipilo* from Southern and Lower California. <Auk, XII, pp. 109–112, April.
Pipilo fuscus senicula described from San Fernando, Lower California.

1895. ————. Birds of San Fernando, Lower California. <Auk, XII, pp. 134–143, April.
Contains notes on the physiography and vegetation and an annotated list of birds.

1895. ————. *Junco hyemalis shufeldti* in Lower California. <Auk, XII, p. 183, April.
Notes on occurrence of this and other juncos in the peninsula.

1895. ————. The Status of *Heleodytes affinis*. <Auk, XII, p. 280, July.
Showing the subspecific relationship with *H. brunneicapillus*.

1895. ————. New Races of *Colaptes* and *Passerella* from the Pacific coast. <Auk, XII, pp. 347–349, October.
Original description of *Colaptes chrysoides brunnescens*, from Lower California.

1895. Cooper, J. G. Catalogue of Marine Shells, Collected Chiefly on the Eastern Shore of Lower California for the California Academy of Sciences during 1891–92. <Proc. Calif. Acad. Sci., 2d ser., V, pp. 34–48, May 21.
A brief account of previous collections made in the gulf and a list of 191 species, with brief annotations.

1895. Eisen, Gustav. Explorations in the Cape Region of Baja California in 1894, with References to Former Expeditions of the California Academy of Sciences. <Proc. Calif. Acad. Sci., 2d ser., V, pp. 733–775, with 5 maps, October 30.
A general account of the physical characteristics of the area named, with notes on the climate and natural history and a review of the former expeditions from the Academy. A valuable contribution to our knowledge of the area covered, and a general map of the peninsula in addition to four others of the cape region.

1895. Gould, George H. To the Gulf of Cortez. <Hunting in Many Lands: The Book of the Boone and Crockett Club, pp. 55–83.
Contains a popular account of a mountain sheep hunt on the desert mountains east of the head of Trinidad Valley, Lower California.

1895. Mearns, Edgar A., M. D. Description of a New Heron (*Ardea virescens anthonyi*) from the Arid Region of the Interior of North America. <Auk, XII, pp. 257–259, July.
Described from Seven Wells, northeastern Lower California.

1895. Radlkofer, L. Three New Species of Sapindaceæ from Western Mexico and Lower California. <Contr. Nat. Herb., I, pp. 367–368, January.
Two are from Lower California.

1895. Stowell, John M. Description of a New Jack Rabbit from San Pedro Martir Mountain, Lower California. <Proc. Calif. Acad. Sci., 2d ser., V, pp. 51–52, May 28.
Describes *Lepus martirensis* from La Grulla.

1895. Van Denburgh, John. A Review of the Herpetology of Lower California. Part I, Reptiles. <Proc. Calif. Acad. Sci., 2d ser., V, pp. 77–162, with 11 plates, May 28.
A general discussion of the relations of the reptilian fauna of the peninsula, with an annotated list of 62 species.

1895. ————. A Review of the Herpetology of Lower California. Part II, Batrachians. <Proc. Calif. Acad. Sci., 2d ser., V, pp. 556–561, September 10.
An annotated list of six species.

1896. Anthony, A. W. Eggs of the Black, Socorro, and Least Petrels. <The Nidologist, IV, pp. 16–17, October.
An account of the nesting and the eggs of the species named, as observed on San Benito Island. (See p. 59 of same volume of Nidologist for corrected egg measurements.)

1896. Bendire, Charles. Life Histories of North American Birds, from the Parrots to the Grackles, with Special Reference to their Breeding Habits and Eggs. [Part 2]. Smithsonian Contributions to Knowledge, XXXII. [Special Bulletin U. S. National Museum, No. 3], pp. 518, with seven colored plates, 4°. Washington.
Contains some original information concerning several Lower Californian species.

1896. Coulter, John M. Preliminary Revision of the North American Species of Echinocactus, Cereus, and Opuntia. <Contr. U. S. Nat. Herb., III, pp. 355–462, April 1.
Contains descriptions of the Lower California species; some described as new.

1896. Van Denburgh, John. Additional Notes on the Herpetology of Lower California. <Proc. Calif. Acad. Sci. 2d ser., V, pp. 1004–1008, January 15.
An annotated list of species collected by Stowell and Lunt during a trip to the San Pedro Martir Mountains in June and July, 1893.

1897. ANTHONY, A. W. Land Birds at Sea. <The Osprey, I, pp. 57–58, January.
Notes on a few species seen off Lower California.

1897. ————. New Birds from the Islands and Peninsula of Lower California. <Auk, XIV, pp. 164–168, April.
Original descriptions of *Carpodacus mcgregori*, *Thryothorus cerroensis*, and *Harporhynchus lecontei arenicola*.

1897. DAVIDSON, GEORGE. The Submerged Valleys of the Coast of California, U. S. A., and of Lower California, Mexico. <Proc. Calif. Acad. Sci., 3d ser., I, Geology, pp. 73–103, with 9 plates, June 25.
The last five pages of this paper are devoted to a brief account of the submarine valleys along the northwest coast of the peninsula.

1897. EISEN, GUSTAV. Explorations in the Cape Region of Baja California. <Bull. Am. Geog. Soc., XXIX, No. 3, p. 271–280, with map, September.
A brief account of the climate, physiography, geology, and a few notes on some of the useful plants of this region.

1897. GAYLORD, HORACE A. Notes on Cormorants. <The Nidologist, IV, p. 102, May.
Brief notes on the cormorants frequenting San Geronimo Island.

1897. ————. The American Osprey in Lower California. <The Osprey, I, p. 131, June.
Brief notes on occurrence and nesting of the osprey on islands off the west coast.

1897. ————. Notes from Guadalupe Island. <The Nidologist, IV, pp. 41–42, January.
Brief comments on birds noted between San Geronimo and Guadalupe Islands and on the latter in July, 1896.

1897. KAEDING, H. B. In Mexican Waters. The Nidologist, IV, p. 109, May.
Brief notes on a few birds noted on Todos Santos, San Martin, and Natividad Islands.

1897. MCGREGOR, R. C. Nest and Eggs of the San Benito Sparrow. <The Osprey, II, November.
Notes on the nesting of this sparrow and the occurrence of other species of birds on San Benito Islands.

1897. MERRILL, GEORGE P. Notes on the Geology and Natural History of the Peninsula of Lower California. <Ann. Rept. U. S. Nat. Mus. for 1895 [1897], pp. 969–994, with cuts and map.
A general account of a trip during the summer of 1892 from San Quintin to El Rosario, San Fernando, the onyx mines, and El Tule Arroyo, near the gulf coast, and return.

1897. MILLER, GERRIT S., JR. Some Bats from Lower California. <American Naturalist, XXXI, 75–77, January.
Records the capture by A. W. Anthony at San Fernando, in May and June, 1894, of *Chæronycteris mexicana*, *Antrozous pallidus* [= *A. p. pacificus*], *Vespertilio nitidus* [= *Myotis californicus*], and *Vesperugo hesperus* [=*Pipistrellus hesperus*].

1897. MERRIAM C. HART. A New Fur Seal or Sea Bear (*Arctocephalus townsendi*) from Guadalupe Island, off Lower California. <Proc. Biol. Soc., Washington, XI, pp. 175–178, July 1.
Contains historical notes and scientific description of the new species, which was based on a skull. No complete specimens of this animal are known to exist.

1897. ————. Revision of the Coyotes or Prairie Wolves, with Descriptions of New Forms. <Proc. Biol. Soc., Washington, vol. XI, pp. 19–33.
Contains the original description of *Canis peninsulæ* from Santa Anita, near San Jose del Cabo.

1897. ————. Description of a New *Bassariscus* from Lower California, with Remarks on *Bassaris raptor* Baird. <Proc. Biol. Soc., Washington, Vol. XI, pp. 185–187.
Describes *Bassariscus saxicola* from Espiritu Santo Island.

1897. OBERHOLSTER, HARRY C. Critical Notes on the Genus *Auriparus*. <Auk, XIV, pp. 390–394, October.
Original description of *Auriparus flaviceps lamprocephalus* from Lower California.

1897. THOMAS, OLDFIELD. Descriptions of New Bats and Rodents from America. <Ann. & Mag. Nat. Hist., 6th ser., XX, pp. 544–553.
Contains original descriptions of *Dasypterus ega xanthinus* and *Oryzomys peninsulæ* from the Southern end of Lower California.

1898. ALLEN, J. A. Descriptions of New Mammals from Western Mexico and Lower California. <Bull. Am. Mus. Nat. Hist., X, pp. 143–158, April 12.
Contains original descriptions of 13 new species and subspecies from Lower California collected by Anthony.

1898. ANTHONY, A. W. Two New Birds from the Pacific Coast of America. <Auk, XV, pp. 36–38, January.
Contains original description of *Oceanodroma kaedingi* from Guadalupe Island.

1898. ————. Four Sea Birds New to the Fauna of North America. <Auk, XV, pp. 38–39, January.
The species mentioned are *Diomedea immutabilis*, *Puffinus auricularis*, *Puffinus cuneatus*, and *Phaëthon rubricaudus*.

1898. ————. Petrels of Southern California. Auk, XV, pp. 140–144, April.
Notes on habits and distribution of petrels off the coast of Lower California.

1898. ————. The Pacific Kittiwake (*Rissa tridactyla pollicaris*) in Lower California. <Auk, XV, p. 267, July.
First record of its occurrence there.

1898. MCGREGOR, RICHARD C. The Guadalupe House Finch. <The Osprey, II, pp. 80–81, February–March.
Brief notes on the nesting of this species in March, 1897.

1898. ————. Phalaropes. <The Osprey, II, pp. 87–88, February–March.
Brief notes on migration and habits, including observations off coast of Lower California.

1898. ————. Young Plumages of Mexican Birds. <Auk, XV, pp. 264–265, July.
Descriptions of young *Ammodramus sanctorum* and *Carpodacus mcgregori*.

1898. McGregor, Richard C. Description of a new *Ammodramus* from Lower California. <Auk, XV, pp. 265–267, July.
Describes *A. halophilus*.

1898. Merriam, C. Hart. The Earliest Generic Name for the North American Deer, with Descriptions of Five New Species and Subspecies. <Proc. Biol. Soc. Washington, XII, April 30, pp. 99–104.
Odocoileus cerrosensis from Cerros Island described.

1898. Miller, G. S., Jr. Description of a new Bat from Lower California. <Ann. & Mag. Nat. Hist., ser. 7, No. 8, pp. 124–125, August.
Original description of *Myotis peninsularis* and mention of four specimens of *Myotis californicus* from the cape region.

1898. Ridgway, Robert. Descriptions of Supposed New Genera, Species, and Subspecies of American Birds, I. Fringillidæ. <Auk XV, pp. 226–227, July.
Original description of *Aimophila ruficeps sororia* from the Victoria Mountains in the cape region.

1898. Thomas, Oldfield. On New Mammals from Western Mexico and Lower California. <Ann. & Mag. Nat. Hist., 7th ser., I, pp. 40–46.
Five new species and subspecies are described from collections made in the cape district, in 1896, by Dane Coolidge.

1898. Weber, A. Les *Echinocactus* de la Basse California. <Bull. Mus. d'Hist. Nat., pp. 99–103, Paris.
Includes description of the large insular species of the gulf, *E. digueti*, named for its discoverer, Leon Diguet.

1899. Anthony, A. W. A Night at Sea. <Bull. Cooper Orn. Club, I, pp. 101–102, November–December.
Observations on birds off the coast of Lower California.

1899. Beck, R. H. Tropical Expedition Wrecked. <Bull. Cooper Orn. Club, I, p. 55, May–June.
An account of the loss on March 16, 1899, of the schooner *Stella Erland* on the coast 30 miles north of Magdalena Bay, with a scientific expedition on board consisting of A. W. Anthony in charge, H. B. Keading, Chase Littlejohn, R. H. Beck, R. C. McGregor, and H. M. Gaylord. The party sailed from San Francisco February 25.

1899. Brandegee, T. S. New Species of Plants from Mexico. <Erythea, VII, pp. 1–9, January.
A list of 19 new species from various localities, including a few collected by A. W. Anthony and C. A. Purpus in Lower California.

1899. Breninger, George F. The Passing of Alfonse Forrer. <Bull. Cooper Orn. Club, I, pp. 66–67, July–August.
Brief biography and portrait. Forrer made extensive collections in Lower California, especially near La Paz.

1899. Diguet, Leon. Rapport sur une Mission Scientifique dans la Basse-Californie. <Nouvelle Archives Missions Scient. et Litt., IX, pp. 1–53, pls. I–X.
Not seen.

1899. Dudley, William Russell. Report on the Plants of Guadalupe Island. <The Fur Seals and Fur Seal Islands of the North Pacific Ocean. Part III, pp. 280–283. Washington.
Contains a short account of previous botanical work on the island and an annotated list of 37 species of flowering plants observed during June, 1897.

1899. McGregor, Richard C. A New Station for the Mexican Crossbill. <The Osprey, III, p. 141, May.
Records the capture of one specimen on Cedros Island.

1899. ————. The Duck Hawk in Lower California. The Oologist, XVI, pp. 181–182, November.
A brief account of the breeding and other habits of this species on the islands along the west coast of the peninsula.

1899. Merrill, George P. A Trip Across Lower California. <The Osprey, III, pp. 20–25, with 5 cuts, October.
A general account of a trip from San Quintin to the onyx mines and return with notes on animal life observed.

1899. Price, W. W. Some Winter Birds of the Lower Colorado Valley. <Bull. Cooper Orn. Club, I, pp. 8–93, September–October.
General notes on the country and an annotated list of species noted on both sides of the Colorado River from Yuma to its mouth.

1899. Southworth, John R. El Territorio de la Baja California, Mexico, Ilustrada. Pp. 88, with numerous cuts and map, folio. San Francisco.
This publication is an illustrated advertising volume printed in Spanish and English, in parallel columns, with numerous portraits and views. It contains a general account of the peninsula, its towns, prominent people, business enterprises, resources, etc.

1899. Thoburn, Wilbur Wilson. Report of an Expedition in Search of the Fur Seal of Guadalupe Island, Lower California, June, 1897. <Fur Seals and Fur Seal Islands of the North Pacific Ocean, Part III, pp. 275–278, with map of Guadalupe Island, quarto. Washington.
A brief general account of Guadalupe Island with notes on the seals observed there, a list of fishes collected, and an annotated list of 10 species of birds observed.

1899. Townsend, Charles H. Pelagic Sealing, with Notes on the Fur Seals of Guadalupe, the Galapagos, and Lobos Islands. <The Fur Seals and Fur Seal Islands of the North Pacific Ocean, Part III, pp. 223–274, pls. XXII–XXXV. Chart of the distribution of the northern fur seals and map of Guadalupe Island, quarto. Washington.
Contains a general account with statistics of pelagic sealing and an account of Townsend's trip to Guadalupe Island in search of fur seals in 1892, when he secured the type of *Arctocephalus townsendi* and several sea elephants, with notes on number of fur seals taken since 1874 in this region.

1900. Anthony, A. W. A Night on Land. <The Condor, II, pp. 28–29, March.
A popular account of observations on the birds of San Benito Islands in late July, with notes on breeding habits.

1900. ANTHONY, A. W. Eggs of the Black Oyster Catcher. <The Condor, II, p. 43, March.
Short description of nest and eggs with photograph, from Ascension Island.

1900. ————. Nesting Habits of the Pacific Coast Species of the Genus *Puffinus*. <Auk, XVII, pp. 247–252, with plate, July.
Observations mainly on the islands off the west coast of Lower California and the mainland of Mexico.

1900. BARROWS, DAVID P. The Colorado Desert. <National Geographic Mag., XI, No. 9, pp. 337–351, with map and illustrations, September.
Historical popular account of the region of the Lower Colorado River.

1900. BELDING, LYMAN. A Part of My Experience in Collecting. <The Condor, II, pp. 1–5, January–February, with portrait.
An autobiographical sketch with notes on the author's work in Lower California.

1900. BRANDEGEE, KATHARINE. Notes on Cacteæ, II. <Zoe, V, pp. 1–9, June.
Notes on various species, mainly from Lower California, and descriptions of five new species and subspecies.

1900. BRANDEGEE, T. S. Voyage of the Wahlberg. <Zoe, V, pp. 19–28, July.
An account of the scientific expedition made in this schooner under A. W. Anthony sailing in March, 1897, from San Diego and visiting the islands along the west coast of Lower California and the Revillagigedo group. Contains brief notes on the islands visited and lists of the species of plants collected.

1900. ————. A New *Tapirira* from Baja California. <Zoe V, pp. 78–79, September–October.
The original description of the Ciruela of the cape district.

1900. COPE, EDWARD DRINKER. The Crocodilians, Lizards, and Snakes of North America. <Rep. U. S. Nat. Mus. for 1898, pp. 153–1270, 800. Washington.
In the section on geographical distribution the author names the southern end of the peninsula, the "Lower Californian District" and gives the relations of the reptilian fauna on pages 1220–1221. The species are described and distribution given.

1900. DIGUET, LEON. La Basse-Californie. <Annales de Geographie, IX, pp. 243–250, Paris, May.
Not seen.

1900. EISEN, GUSTAV. Explorations in the Central Part of Baja California. <Bull. Amer. Geog. Soc. XXXII, No. 5, pp. 397–429, with map.
A general account of the climate and physiography with the best map of southern Lower California published to that date.

1900. STOKES, SUSAN G. A New Species of *Chorizanthe* from Lower California. <Zoe, V, p. 60, August.
Describes *Chorizanthe inequalis* from San Telmo.

1901. ANTHONY, A. W. The Guadalupe Wren. <The Condor, III, p. 73, May.
An account of the extinction of this species on Guadalupe Island.

1901. BRANDEGEE, T. S. New Species of Plants, Mainly from Baja California. <Zoe, V, pp. 104–109, February–April.
Contains descriptions of 10 new species from Lower California.

1901. EISEN, GUSTAV. Cerros, or Cedros Island. <Bull. Amer. Geog. Soc., XXXIII, No. 1, p. 64.
A discussion of the proper spelling, proving that the form Cedros is correct.

1902. ALLEN, J. A. The Hair Seals (Family Phocidae) of the North Pacific Ocean and Bering Sea. <Bull. Amer. Mus. Nat. Hist., XVI, December 12, pp. 459–499.
Contains original description of *Phoca richardii geronimensis* from San Geronimo Island.

1902. BELDING, LYMAN. The Fall Migration of *Oreortyx pictus plumiferus*. <The Condor, V, p. 18, January.
Mentions the occurrence of *Anthus pensilvanicus* at Cape San Lucas.

1902 BREWSTER, WILLIAM. Birds of the Cape Region of Lower California. <Bull. Mus. Comp. Zool., XLI, No. 1, pp. 1–241, with map, September.
This excellent summary of the bird life of southern Lower California is the best and most complete account of the birds of any part of the peninsula. It is based on the collections and notes of M. Abbott Fraser and contains much original matter on life histories and the original descriptions of *Megascops xantusi, Bubo virginianus elachistus,* and *Tachycineta thalassina brachyptera.*

1902. HYDROGRAPHIC OFFICE, UNITED STATES NAVY DEPARTMENT. The West Coasts of Mexico and Central America from the United States to Panama, including the Gulfs of California and Panama. 3d edition, p. 438, 800. Washington.
Contains a great amount of detailed information concerning the islands, coasts, and adjacent interior in addition to sailing directions.

1902. LUMMIS, C. F. Early Western History. Diary of Junipero Serra: Loreto to San Diego, March 28–June 30, 1769. <Out West Magazine, Vol. XVI, pp. 293–296, 399–406, 513–518, 635–642; Vol. XVII, pp. 69–76.
A translation of the original manuscript. Contains some interesting notes on the country and Indians but nothing of value on the natural history.

1902. MILLER, GERRIT S., JR. Twenty New American Bats. <Proc. Acad. Nat. Sci., Philadelphia, pp. 389–412, May 20.
Includes original description of *Antrozous minor* from Comondu and *Natalus mexicanus* from Santa Anita.

1902. SLADE, CHARLES B. Hunting Sheep and Antelope in Lower California. <Outing, XXXIX, pp. 505–512, February.
Narrative of a hunting trip from San Quintin to Matomi and San Juan de Dios.

1902. Trelease, William. The Yucceæ. <Thirteenth Annual Report, Missouri Botanical Garden, pp. 27–133, with 99 plates, including maps,
A monographic revision of the group with descriptions of the species, photographs, and maps showing their distribution, including Lower California.

1903. Brandegee, T. S. Notes and New Species of Lower California Plants. <Zoe, V, pp. 155–174, May.
Thirty-seven species and varieties are described as new from the cape district.

1903. Brewster, William. Breeding Grounds of the Black and Socorro Petrals—a Correction. <Auk, XX, pp. 63–64, January.
Corrects erroneous statement that these birds breed on Los Coronados Islands in the Gulf of California. The group near San Diego was intended. (See Birds of the Cape Region of Lower California, p. 33.)

1903. Elliot, D. G. Descriptions of Apparently New Species and Subspecies of Mammals from California, Oregon, the Kenai Peninsula, Alaska, and Lower California, Mexico. <Field Columb. Mus. Pub., Zool. ser., III, pp. 153–173, April.
Onychomys macrotis, Peromyscus hemionotis, P. gaurus, P. homochroia, P. oresterus, Microtus californicus huperuthrus, Reithrodontomys peninsulae, Perognathus helleri, P. baileyi rudinoris, P. femoralis mesopolius, P. knekus, Spilogale arizonae martirensis, Sorex oreinus, and *Myotis milleri* described from northern Lower California.

1903. ————. A List of Mammals Collected by Edmund Heller in the San Pedro Martir and Hanson Laguna Mountains and the Accompanying Coast Regions of Lower California with Descriptions of Apparently New Species. <Field Columb. Mus. Pub., 79, Zool. ser., III, No. 12, pp. 199–232, pls. XXXIII–XXXVII, with map, June.
An important paper giving the results of the work done in northern Lower California during 1902 with a description of the country, map, and annotated list of mammals from Heller's notes.

1903. ————. Descriptions of Twenty-seven Apparently New Species and Subspecies of Mammals. <Field Columb. Mus., Zool. ser. III, No. 14, pp. 239–261, December.
Contains original descriptions of *Ovis cervina cremnobates* and *Dipodomys m. arenivagus* from Lower California.

1903. Grinnell, J., and F. S. Daggett. An Ornithological Visit to Los Coronados Islands, Lower California. <Auk, XX, pp. 27–37, January.
Contains a description of the islands and an annotated list of 22 species of birds, including description of a new subspecies of song sparrow (*Melospiza melodia coronatorum*), observed there in August, 1902.

1903. Parish, S. B. A Sketch of the Flora of Southern California. <Bot. Gaz., XXXVI, pp. 203–222, 259–279, October.
Contains a general description of the physiography of the region and characteristics and relationships of the flora with a list of 16 Lower California species which enter California along the coast (p. 261).

1904. Clinch, Bryan J. California and its Missions. 2 vols. 8vo. Vol. 1, pp. 228, with cuts. San Francisco.
The first volume is devoted to an account of Lower California and the work of the Spanish missionaries there.

1904–5. Freeman, Louis R. A New Sportsman's Paradise. <Western Field, V, pp. 191–197, 269–271, 352–360, 1904; 445–451, 1905. Sketch maps and photographs.
A popular account of a hunting trip in the delta region of the Colorado with some notes on the game birds and mammals

1904. MacDougal, Daniel Trembly. Botanical Explorations in the Southwest. <Journal New York Botanical Garden, V, No. 53, pp. 89–98, with plate and cuts, May.
Contains a brief account of a boat trip from Yuma, Ariz., to San Felipe Bay, Lower California, and return in January and February, 1904.

1905. Brandegee, Katherine. Notes on Cacteæ. <Zoe, V, pp. 189–195, August.
Contains descriptions of several new species from Lower California and other parts of Mexico.

1905. Brandegee, T. S. Palms of Baja California <Zoe, V, pp. 187–189, August.
Notes on the various native species and original description of *Erythea brandegeei* from the cape district.

1905. Ellison, O. C. In the Sea of Pearls. <Sunset Magazine, pp. 165–175, December.
A popular account of the southern gulf coast of Lower California and its pearl fisheries.

1905. Fisher, Walter K. In Memoriam: Walter E. Bryant. <Condor, VII, pp. 129–131, with portrait, September.
A brief biography giving dates of Bryant's work in Lower California.

1905. Goldman, E. A. Two New Wood Rats of the Genus *Neotoma*. <Proc. Biol. Soc., Washington, XVIII, February 2, pp. 27–34.
Includes original descriptions of *Neotoma martinensis*, from San Martin Island, and *N. nudicauda* from Carmen Island.

1905. Grinnell, J. Where Does the Large-Billed Sparrow Spend the Summer? <Auk, XXII, pp. 16–21, January.
A general discussion of its distribution and possible breeding places.

1905. Grinnell, Joseph. The Ornithological Writings of Walter E. Bryant. <Condor, VII, pp. 131–132, September.
This bibliography contains numerous titles of papers on Lower California subjects.

1905. Kaeding, Henry B. Birds from the West Coast of Lower California and the Adjacent Islands. <Condor, VII, pp. 105–111, 134–138, July and September.
A short account of islands visited, including the Revillagigedo group and briefly annotated list of birds seen, with a short bibliography.

1905. MacDougal, Daniel Trembly. Botanical Exploration in Arizona, Sonora, California, and Baja California. <Journ. N. Y. Bot. Garden, VI, No. 66, pp. 91–102, with cuts, June.
Contains a brief account of the expedition down the lower Colorado, and tributaries to near the base of the Cocopah Mountains, in company with E. A. Goldman, March and April, 1905.

1905. Meek, Seth Eugene. An Annotated List of a Collection of Reptiles from Southern California and Northern Lower California. <Field Columbian Museum, Zool. ser., VII, No. 1, pp. 1–19, 3 plates, November.
A list of the species collected by E. Heller in Lower California north of Matomi, southern end of the San Pedro Martir Mountains.

1905. Pattie, James O. Pattie's Personal Narrative of a Voyage to the Pacific and in Mexico, June 20, 1824–August 30, 1830. <Early Western Travels, 1748–1846, XVIII, pp. 1–364, 800. Cleveland.
This is a reprint of the original edition of 1831. The narrative contains an interesting account of an expedition of an American trapper through what is now the southwestern United States, northern Lower California, and parts of the mainland of Mexico.

1905. Stone, Witmer. On a Collection of Birds and Mammals from the Colorado Delta, Lower California, with Field Notes by Samuel N. Rhoads. <Proc. Phil. Acad. Nat. Sci., pp. 676–690, September.
A briefly annotated list of 22 species of mammals and 107 birds. The results of a trip to the mouth of the Colorado early in 1905 by S. N. Rhoads.

1905. Townsend, Charles Haskins. Notes on Certain Pinnipeds, with Data Respecting Their Present Commercial Importance. <Ninth Ann. Rept. New York Zoological Society, pp. 105–116, with 3 plates, (1904).
Gives brief notes concerning the northern sea elephant and the Guadalupe fur seal.

1905. Van Dyke, T. S. Sport on the Lower Colorado. <Western Field, VI, pp. 3–7, February.
A popular account of a hunting trip from Yuma, Ariz., to the head of the Gulf of California, in December, 1904, during which great numbers of ducks, geese, and waders were noted.

1906. Anthony, A. W. Random Notes on Pacific Coast Gulls. <Auk, XXIII, pp. 129–137, April.
A general account of the distribution and habits of gulls including those seen along the coast of Lower California.

1906. ————. Where Does the Large-Billed Sparrow Spend the Summer? <Auk, XXIII, pp. 149–152, April.
Discusses the probable breeding ground of this species, especially in northwestern Lower California.

1906. Berlepsch, Hans von. On a New Form of *Oceanodroma* Inhabiting San Benito Island, Off the Coast of Lower California. <Auk, XXIII, pp. 185–186, April.
Original description of *Oceanodroma monorhis chapmani*.

1906. Brandegee, T. S. New Species of Mexican Plants Collected by Dr. C. A. Purpus. <Zoe, V, pp. 231–241, September.
Includes original description of *Cassia purpusi* from Lower California.

1906. MacDougal, Daniel Trembly. The Delta of the Colorado, with Map by Godfrey Sykes. <Bull. Amer. Geog. Soc., XXXIII, No. 1, pp. 1–16, with cuts and maps, January.
A general account of the delta and of the adjacent area in Lower California, with notes on the principal plants observed. This paper was reprinted in "Contributions from the New York Botanic Garden," No. 77, pp. 1–16.

1907. MacDougal, D. T. The Desert Basins of the Colorado Delta. <Bull. Amer. Geog. Soc., XXXIX, No. 12, p. 705–729, with map and illustrations, December.
Popular account of the region with discussion of early history.

1907. Mearns, Edgar Alexander. Mammals of the Mexican Boundary of the United States. A descriptive catalogue of the species of mammals occurring in that region, with a general summary of the natural history and a list of trees. United States National Museum Bulletin 56, pp. I–XV, 1–530, April 13.
Includes narrative of explorations conducted along the boundary line between the United States and Lower California from March to July, 1894. Many species of mammals and plants of Lower California discussed in the annotated lists.

1907. Merriam, C. Hart. Descriptions of Ten New Kangaroo Rats. <Proc. Biol. Soc. Washington, XX, pp. 75–80, July 22.
Contains original descriptions of *Dipodomys platycephalus, D. maragaritæ, D. insularis* and *Perodipus simulans peninsularis* from Lower California.

1907. Nelson, E. W. Descriptions of New North American Rabbits. <Proc. Biol. Soc. Washington, XX, pp. 81–84, July 22.
Contains original descriptions of *Lepus californicus magdalenæ, Sylvilagus mansuetus*, and *S. bachmani exiguus* from the peninsula.

1907. North, Arthur Walbridge. Hunting the Bighorn. <Sunset Magazine, October, pp. 523–532, with cuts.
A popular account of hunting mountain sheep in various parts of Lower California, including the killing of an extremely dark specimen on the east base of the San Pedro Martir Mountains.

1907. ————. The Uncharted Sierra of San Pedro Martir. <Bull. Amer. Geog. Soc., XXXIX, No. 9, pp. 544–554, September.
A general account of these mountains.

1907. ————. Map of San Pedro Martir Sierra, Lower California. <Bull. Amer. Geog. Soc., XXXIX, No. 12, facing page 768, December.
This is a small outline map to accompany the author's article on the same region in this bulletin, Vol. XXXIX, No. 9, for September 1907.

1907. ————. Resources of Lower California. <Monthly Bull. Intern. Bur. Amer. Republics, XXV, No. 6, pp. 1374–1376, December.
A brief general account of the peninsula and its main resources.

1907. ————. The Mother of California. 8vo, pp. 169, with map and halftone illustrations. New York and San Francisco.
A general historical account of the peninsula with chapters on the physical character of the country, mines, and present conditions, with a bibliography.

1907. Oberholser, Harry C. Description of a New *Otocoris* from Lower California. <Proc. Biol. Soc. Washington, XX, pp. 41–42, March 27.
Describes *Otocoris alpestris enertera* from near Magdalena Bay.

1907. Osgood, Wilfred H. Four New Pocket Mice. <Proc. Biol. Soc. Washington, XX, pp. 19–22, February 23.
Contains original descriptions of *Perognathus penicillatus siccus, P. p. ammophilus,* and *P. spinatus magdalenæ,* from Lower California.

1907. Parish, S. B. A Contribution Toward a Knowledge of the Genus *Washingtonia*. <Bot. Gaz., XLIV, pp. 408–434, with illustrations, December.
A discussion of the status and origin of the types of the various forms, most of which are probably from Lower California. Retains the generic name *Washingtonia*.

1907. Thayer, John E., and Outram Bangs. A New Race of the Californian Thrasher from Lower California. <Proc. New England Zool. Club, IV, pp. 17–18, April 30.
Describes *Toxostoma rediviva helva* from Rosario.

1907. ————. Birds Collected by W. W. Brown, jr., on Cerros, San Benito, and Natividad Islands in the Spring of 1906, with Notes on the Biota of the Islands. <Condor, IX, pp. 77–81, May.
Briefly annotated lists with some general notes on the islands.

1907. ————. Catalogue of Birds Collected by W. W. Brown, jr., in Middle Lower California. <Condor, IX, pp. 135–140, September.
A briefly annotated list of species observed during the autumn of 1905 and spring of 1906.

1908. Engelhardt, O. F. M. (Fr. Zephyrin). The Missions and Missionaries of California, Vol. I, Lower California. Pp. 654, with cuts and maps.
This publication contains a good account of the work of the Spanish missionaries in Lower California from their first arrival in 1535 to 1859. It is based on original records and published material.

1908. Lydekker, R. Sea Elephants for the British Museum. <London Field, III, p. 276, February 15.
A brief general account of the species based on specimens secured on Guadalupe Island, by Harris in May, 1907.

1908. North, Arthur W. Magdalena Bay. <Sunset Magazine, March, pp. 411–420, with plates and cuts.
A popular account of the history and surroundings of Magdalena Bay.

1908. North, Arthur Walbridge. The Native Tribes of Lower California. <American Anthropologist, X, pp. 236–250, April–June.
A résumé of the historical accounts of the natives of this region with original notes on present conditions, and notes and cuts of petroglyphs in various parts of the peninsula.

1908. Rothschild, Hon. Walter. *Mirounga angustirostris* (Gill). <Novitates Zoologicæ, XV, pp. 393–394, Plates I–VIII, November 18.
Contains a brief account of this sea elephant based on the series of seven specimens secured for Tring Museum, by Charles Harris, at Guadalupe Island, June 2–17, 1907, accompanied by reproductions of photographs of the living animals taken by Harris.

1908. Thayer, John E., and Outram Bangs. The Present State of the Ornis of Guadalupe Island. <Condor, X, pp. 101–106, May–June.
Contains a brief description of the island and an annotated list of the birds observed there, by W. W. Brown, jr., during May and June, 1906.

1909. Goldman, E. A. Five New Wood Rats of the Genus *Neotoma* from Mexico. <Proc. Biol. Soc. Washington, XXII, pp. 139–143, June 25.
Neotoma intermedia pretiosa, from Matancita, 50 miles north of Magdalena Bay; *N. i. perpallida,* from San Jose Island; *N. i. vicina,* from Espiritu Santo Island; and *N. abbreviata,* from San Francisco Island are included in the new forms described.

1909. Grinnell, J. The Zone-tailed Hawk in California. <Condor, XI, p. 69, March.
Records a specimen from southeast of Tijuana, Lower California.

1909. Harris, Charles Miller. A Cruise After Sea Elephants. <Pacific Monthly Magazine, April, pp. 321–339, with cuts.
A popular account of a trip to Guadalupe Island in May, 1907, when a number of specimens of sea elephants were collected for Tring Museum.

1909. Lamb, Chester. Nesting of the Xantus Murrulet as Observed on Los Coronados Islands, Lower California. <The Condor, XI, pp. 8–9, January.
Date and character of nesting places at this locality visited in June, 1908.

1909. Lydekker, R. On the Skull Characters in the Southern Sea Elephant. <Proc. Zool. Soc. London, May 25, pp. 600–606.
Southern and northern sea elephants regarded as specifically distinct.

1909. Nelson, E. W., and E. A. Goldman. Eleven New Mammals from Lower California. <Proc. Biol. Soc. Washington, XXII, pp. 23–28, March 10.
Original descriptions of *Eutamias merriami meridionalis, Ammospermophilus leucurus insularis, Thomomys magdalenæ, T. bottæ russeolus, Vulpes macrotis devius, Bassariscus astutus palmarius, B. astutus insulicola, Sorex lagunæ, S. californicus juncensis, Myotis capitaneus, M. micronyx.*

1909. Osburn, Pingree I. Notes on the Birds of Los Coronados Islands, Lower California. <Condor, XI, pp. 134–138, July.
An annotated list of species observed in the spring of 1908

1909. Osgood, Wilfred H. Revision of the Mice of the American Genus *Peromyscus*, North American Fauna No. 28, pp. 1–285, pls. 1–8, April 17.
Includes original descriptions of *Peromyscus maniculatus margaritæ* from Margarita Island, *P. m. magdalenæ* from Magdalena Island, *P. eremicus avius* from Ceralbo Island, *P. e. polypolius* from Margarita Island, *P. e insulicola* from Espiritu Santo Island, and *P. truei lagunae* from La Laguna.

1909. Thayer, John E. Some Rare Birds and Sets of Eggs from the Cape Region of Lower California. <Condor, XI, pp. 10–11, January.
A few notes on some species taken by W. W. Brown, jr., at La Paz and in the Sierra Laguna.

1909. ———. Correspondence. <Condor, XI, pp. 142–143, July.
Several letters written from La Paz, giving details of ornithological collecting by W. W. Brown, jr., during the winter of 1909.

1909. ———. Frazar's Oyster Catcher's Eggs. <Oologist, XXVI, pp. 188–189, November 15.
Note on the number of eggs laid in a set by this species.

1909. Thayer, John E., and Outram Bangs. Description of a New Subspecies of the Snowy Heron. <Proc. New England Zool. Club, IV, pp. 39–41, April 29.
Describes *Egretta candidissima brewsteri* from San Jose Island.

1909. Van Rossem, A. Some Unrecorded Species from Los Coronados Islands, Mexico. <Condor, XI, p. 208, November.
A briefly annotated list of nine species.

1909. Wright, Howard W. An Ornithological Trip to Los Coronados Islands, Mexico. <Condor, XI, pp. 96–100, May.
An annotated list of species observed in June, 1908.

1910. Howell, Alfred B. Notes from Los Coronados Islands. <Condor, XII, pp. 184–187, November.
Notes on breeding habits of birds found there the spring of 1910, especially of Xantus murrelet.

1910. Lamb, Chester. A Glimpse of Bird Life on the West Coast of Mexico. <Condor, XII, pp. 74–79, March.
A popular account of a trip and birds seen from San Diego Calif., to San Blas and the Las Marietas Islets off Cape Corrientes, in the spring of 1909, with notes on the birds.

1910. North, Arthur Walbridge. Camp and Camino in Lower California. 8vo., pp. 346, with map and halftone plates. New York.
A popular account of journeys throughout the length of the peninsula in 1905–6 with a bibliography.

1911. Andrews, Roy C. Description of an Apparently New Porpoise of the Genus *Tursiops* with Remarks upon a Skull of *Tursiops gillii* Dall. <Bull. Amer. Mus. Nat. Hist., XXX, pp. 233–237, with plate, August 26.
Original description of *Tursiops nuuanu* and record of its occurrence and that of *T. gillii* in Lower California.

1911. D[ickerson], M[ary] C. Rare Elephant Seals for the Museum. <American Museum Journal, XI, No. 4, pp. 109–112, April.
A brief notice of the capture of elephant seals on Guadalupe Island by the *Albatross* expedition the 1st of March, 1911, with the first photographs ever published showing the "trunk" of the old males, taken by C. H. Townsend.

1911. Grinnell, George Bird. The Newly Discovered Elephant Seals. <Forest and Stream, LXXVI, No. 17, p. 652, April 29.
A brief account of the discovery by the *Albatross* expedition of elephant seals on Guadalupe Island, in March, 1911, and the capture of six young for the New York Aquarium, with photographs of the old males on the beach.

1911. Howell, Alfred B. Some Birds of the San Quintin Bay Region, Baja California. <Condor, XIII, pp. 151–153, September, 1911.
General notes on species observed during April, May, and July, 1910 (on p. 211 of same volume the name *Numenius americanus* of of this article corrected to *N. hudsonicus*).

1911–12. Humphrey, W. E. Shooting the Vanishing Sheep of the Desert. <Outdoor Life, XXVIII, No. 6, pp. 477–487, December, 1911; XXIX, No. 1, pp. 3–16, January, 1912; No. 2, pp. 95–105, February, 1912.
A good popular account of a hunt in the Sierra Tinaja in northeastern Lower California with notes on the country and habits of the sheep, with illustrations from photographs.

1911. Mott, Russell ("Double Barrel"). Boregas and Tanakas. <Forest and Stream, LXXVI, No. 12, pp. 448–451, March 25.
A good account of a hunting trip after mountain sheep to the Tinajas Mountains west of the mouth of the Colorado River, Lower California.

1911. Nelson, E. W. A Land of Drought and Desert—Lower California. Two Thousand Miles on Horseback Through the Most Extraordinary Cacti Forests in the World. <The National Geographic Magazine, XXII, 443–474, with 28 illustrations, May.
A popular account of the journey of the author and E. A. Goldman the entire length of the peninsula in 1905–6.

1911. Oberholser, Harry C. A Revision of the Forms of the Ladder-backed Woodpecker (*Dryobates scalaris* [Wagler]). <Proc. U. S. Nat. Mus., XLI, pp. 139–159, June 30.
Contains original description of *D. s. eremicus* from San Fernando, Lower California.

1911. Osburn, Pingree I. Collecting Socorro and Black Petrels in Lower California. <Condor, XIII, pp. 31–34, January.
Notes on breeding habits on Los Coronados Islands, Lower California, mainly in 1909 and 1910.

1911. Osburn, Raymond C. California Elephant Seals at the New York Aquarium. <Zoological Society Bulletin No. 45, pp. 759–762, with photographs, May.
An account of six young elephant seals captured on Guadalupe Island, Lower California, and received at the New York Aquarium, March 13, 1911, via San Diego.

1911. Ridgway, Robert. Diagnoses of Some New Forms of Picidæ. <Proc. Biol. Soc. Washington, XXIV, pp. 31–35, February 24.
Contains original description of *Centurus uropygialis brewsteri* from the cape district of the peninsula.

1911. Standley, Paul C., and E. A. Goldman. Two New Shrubs from Lower California. <Contr. U. S. Nat. Herb., XIII, pt. 10, p. 375, June.
Original descriptions of *Manihot chlorosticta* and *Mesosphaerum insulare* from the southern part of the peninsula.

1911. Thayer, John E. Eggs and Nest of the San Lucas Robin (*Planesticus confinis*). <Oologist, XXVIII, p. 77, April, 15.
Two nests and sets of eggs described.

1911. ————. A Nesting Colony of Herrmann Gulls and Brewster Boobies. <Condor, XIII, pp. 104–106, with photographs, May.
Observations made on San Ildefonso Island, Lower California, the last of March, 1909, by W. W. Brown, jr.

1911. ————. Eggs of the Elegant Tern (*Sterna elegans*). <Oologist, XXVIII, p. 171, November 15.
Describes a series of eggs collected on Ceralbo Island in April, 1910, by W. W. Brown, jr.

1911. Townsend, Charles H. Oceanic Work on the *Albatross*. <The American Museum Journal, XI, No. 5 p. 159, May.
Quotations from letters from the *Albatross* expedition along the coasts of Lower California the spring of 1911, giving notes on itinerary, etc.

1911. ————. Zoological Results of the *Albatross* Voyage. <Zoological Society Bulletin No. 46, pp. 774–776, New York, July.
A brief popular account with photographs.

1911. Trelease, William. The Desert Group Nolineæ. <Proc. Amer. Phil. Soc., L, pp. 404–442, 2 maps and 17 plates, July–August.
A systematic revision of the group, including five forms occurring in Lower California, of which two are described as new.

1912. Allen, J. A. Historical and Nomenclatorial Notes on North American Sheep. <Bull. Amer. Mus. Nat. Hist., XXXI, pp. 1–29, March 4.
Contains notes on the first published records of mountain sheep from Lower California, which was also the first for North America.

1912. Howell, A. B. Notes from Todos Santos Islands. <Condor, XIV, pp. 187–191, September.
An annotated list of the birds observed in April, 1910.

1912. Nelson, E. W. A Correction of Two Recent Names for Mammals. <Proc. Biol. Soc. Washington, XXV, p. 116, June 29.
Perognathus penicillatus seri substituted for *P. p. goldmani* and *Perognathus spinatus occultus* for *P. s. nelsoni*.

1912. ————. A New Subspecies of Pronghorn Antelope from Lower California. <Proc. Biol. Soc. Washington, XXV, pp. 107–108, June 29.
Original description of *Antilocapra americana peninsularis* from 45 miles south of Calmalli.

1912. Phillips, J. C. A New Puma from Lower California. <Proc. Biol. Soc. Washington, XXV, pp. 85–86, May 4.
Original description of *Felis improcera* from Calmalli.

1912. Thayer, John, and Outram Bangs. A New Race of Great Blue Heron from Espiritu Santo Island, Lower California. <Proc. New England Zool. Club, IV, February 23, pp. 83–84.
Description given of *Ardea herodias sancti-lucae* from Espiritu Santo Island.

1912. Townsend, Charles Haskins. The Northern Elephant Seal. <Zoologica, I, No. 8, pp. 159–173, with numerous plates, April 15.
Contains an account of the rediscovery of a herd of these animals on Guadalupe Island, Lower California, March 2, 1912, with a fine series of photographs of the living animals taken by the author.

1912. ————. The Elephant Seal not Extinct. A Herd Discovered on Guadalupe Island, West of Lower California. <The Century Magazine, LXXXIV, pp. 205–211, with photographs, June.
An account of the author's search for these animals in previous years, the discovery of the herd of more than 100 on Guadalupe in March, 1911, and the capture of some young, which were sent to the New York Aquarium.

1912. ————. Mammals Collected by the *Albatross* Expedition in Lower California in 1911, with Descriptions of New Species. <Bulletin American Museum of Natural History, XXXI, pp. 117–130, with 2 plates, June 14.
Contains a list of species collected or observed during the expedition, including the following species or subspecies supposed to be new: *Lepus alleni tiburonensis, Perognathus baileyi insularis, P. penicillatus goldmani, P. spinatus nelsoni, Neotoma albigula seri, Neotoma insularis, Peromyscus guardia, P. stephani, P. eremicus carmeni*, and *Canis jamesi*.

1912. Trelease, William. The Agaves of Lower California. <Twenty-second Annual Report of the Missouri Botanical Garden, pp. 37–65, pls. 19–72, February 14, including descriptions of new species.
Contains descriptions of 25 species, of which 17 are described as new.

1913. BONILLAS, Y. S., and others. Memoria de la Comision del Instituto Geologico de Mexico que Exploro la Region Norte de la Baja California. <Parergones del Instituto Geologico de Mexico, V, Nos. 2–10, pp. 89–534, laminas I–CXII, Secretaria de Fomento, Colonizacion e Industria, Mexico, as follows:

Bonillas, Y. S., and Urbina, F. Informe acerca de los Recursos Naturales de la porte Norte de la Baja California, Especialmento del Delta del Rio Colorado, pp. 162–235, laminas I–XXIV.

Flores, Teodoro, and Gonzalez, Pedro, jr. Exploracion de la porte Central Elevada de la Porcion Norte de la Peninsula de la Baja California, pp. 237–275, laminas XXV–LXV.

Engerrand, Jorge, and Poredes, Trinidad. Informe Relativo a la Porte Occidental de la Region Norte de la Baja California, pp. 278–306, laminas LXVI–LXXXVII.

Bose, E., and Wittich, E. Informe Relativo a la Exploracion de la Region Norte de la Costa Occidental de la Baja California, pp. 307–529, laminas LXXXVIII–CXII.

This report contains the results obtained during 1911 and 1912 in the northern part of Lower California by an expedition divided into four sections sent out by the Geological Institute of the Department of Interior, Mexico, to investigate the physiography, geology, and the water, agricultural, and other resources of this region. The reports are accompanied by maps and plates and give the best and most detailed information extant on the northern half of the peninsula.

This report was reprinted with title page bearing a different vignette and with the following cover title: Memoria de la Comisión del Instituto Geológico de México que Exploró la Region Norte de la Baja California.

1913. PHILLIPS, J. C. The Lower California Pronghorn Antelope. <Science (N. S.), XXXVII, No. 5, pp. 717–718, May 9.

A note giving skull and horn characters of *Antilocapra americana peninsularis* and confirming the validity of this subspecies.

1913. SIMPICH, FRED. The Land of American Cannibals. <Travel, XXI, No. 5, pp. 34–37, with cuts, September.

A brief, interesting account of Lower California, including some references to the physical character and people of Tiburon Island. The illustrations are from photographs taken both on the peninsula and on the island.

1913. WEBSTER, E. BARTLETT. Report on the Northern District of Lower California. Pp. i–xxiii, 1–359, 8vo, December. San Diego, Calif.

A general account of northern Lower California, including the physiography and natural resources.

1913. WILLET, GEORGE. Bird Notes from the Coast of Northern Lower California. <Condor, XV, pp. 19–24, January–February.

An annotated list of 98 birds observed from April 4 to 21, 1912, during a coasting trip from San Diego to the south end of Cedros Island.

1913. WRIGHT, HOWARD W. The Birds of San Martin Island, Lower California. <Condor, XV, p. 207–210, November.

Annotated list of 12 species.

1914. GRINNELL, JOSEPH. An Account of the Mammals and Birds of the Lower Colorado Valley with Especial Reference to the Distributional Problems Presented. Univ. Calif. Pub. Zool., vol. 12, pp. 218–294, with map and illustrations, March 20.

Extended discussion of physiography and associational areas, with annotated lists of birds and mammals.

1915. FUNCKE, E. W. The Sheep Hunting of Lower California. <Outdoor Life, September, pp. 221–228, with photographs and map.

A general popular article on the habits and hunting of mountain sheep in Lower California with information concerning other game animals and a fairly accurate map showing the distribution of large game on the entire peninsula.

1915. HEIM, Dr. ARNOLD. Sur la Géologie de la Parte Meridionale de la Basse Californie. <Comptes Rendu, vol. 161, p. 419, L'Academie des Sciences, Paris, October.

Gives brief notes on the geology of the peninsula south of La Purisima.

1916. ————. Reisen im Südlichen Teil der Halbinsel Niederkalifornien. <Zeitschrift der Gesellschaft für Erdkunde zu Berlin, No. 1, 4 Tafeln.

A brief account of an expedition through a large part of the peninsula during the summer of 1915 by a party of Swiss geologists and botanists to investigate the character of the country, largely in relation to its agricultural possibilities.

1916. ————. Charakter-Pflanzen der Halbinsel Niederkalifornien. <Vegetations-Bilder, 13 Reihe, Heft 3–4, Tafel 13–24, Jena.

A short introduction on the general character of the peninsula, followed by 12 handsome quarto plates illustrating some of the most notable plants with text.

1916. GOLDMAN, EDWARD A. Plant Records of an Expedition to Lower California. <Contr. W. S. Nat. Herb., vol. 16, part 14, pp. i–viii, 309–371, ix–xiii, pls. 104–133, with map, 8 vo., February 10.

An annotated list of the principal plants collected or noted by E. W. Nelson and E. A. Goldman during the Biological Survey Expedition of 1905–6. Includes descriptions of three new species of oak—*Quercus brandegei, Q. idonea,* and *Q. devia.*

1916. Poder Ejecutivo, Secretaría de Fomento, Colonización y Industria, Dirección Agraria, 18 de mayo de 1916. Permiso concedido al Señor Miguel L. Cornejo para la explotación de las salinas ubicadas al Sur de la Isla de Pichilinque, Bahia de La Paz, Baja California. <Boletin Oficial de la Secretaria de Fomento, Colonización y Industria, Mexico, I, No. 4, pp. 133–135, octubre.

Permit to exploit the salt beds south of Pichilinque Island in La Paz Bay for two years from May 18, 1916.

1916. Poder Ejecutivo, Secretaría de Fomento, Colonización y Industria, Dirección Agraria, 28 de octubre de 1916. Contrato celebrado entre el C. Ing. Pastor Rouaix, Secretario de Fomento, Colonización e Industria, en representación del Executivo de la Unión, y los Señores Gerardo Baltanás y Salvador Cataño, para el arrendamiento de los "Islotes Coronados," sitios en el Océano Pacifico, Distrito Norte de la Baja California. <Boletin Oficial de la Secretaría de Fomento, Mexico, I, No. 3, pp. 97–98, octubre.

Leases the Coronado Islands for five years from October 28, 1916, for the establishment there of a hotel, whaling station, and stone quarries.

1916. Poder Ejecutivo, Secretaría de Fomento, Colonización y Industria, Dirección Agraria, 10 de noviembre de 1916. Contrato celebrado entre el C. Ingeniero Pastor Rouaix, Secretario de Estado y del Despacho de Fomento, Colonización e Industria, en representación del Executivo de la Nación, por una parte, y el Señor Nicolás Fossum, como apoderado del Señor Ragnar M. Fossum, por la otra, para establacer, en la Baja California, una fabrica de productos obtenidos mediante el beneficio de la ballena. <Boletin Oficial de la Secretaría de Fomento, Colonización e Industria, Mexico, I, No. 4, pp. 137–141, noviembre.

This concession permits Ragner M. Fossum [Norwegian] to establish a whaling industry on the west coast of Lower California for 10 years from November 10, 1916. The products are to be oil, guano, and salted, smoked, or dried whale meat for food. No whaling is permitted in the bays nor during the breeding season.

1916. Rolland, M. C. Problema de la Baja California, Canal de California. Pp. 1–12.

This pamphlet without date or imprint gives on its front cover an outline map of Lower California with a canal laid down from the mouth of the Colorado River westward to Ensenada Bay. The author gravely advocates the building of this canal, apparently oblivious of the great north and south mountain range about 6,000 feet high directly across its course, in order to develop the commerce of Lower California and northern Mexico. This is a good illustration of the impractical folly shown in a large part of the writings advocating the development of Lower California and shows complete ignorance of the real conditions there.

1916. Townsend, C. H. The Guadalupe Fur Seal: A Contribution to Its History. <Zoological Society Bulletin (New York), XIX, No. 2, pp. 1330–1331.

A brief record of the number of skins of this seal known to have been taken, including 8,338 taken by the whaler *Port au Prince* at San Benito Islands in 1806.

1916. Townsend, Charles Haskins. Voyage of the *Albatross* to the Gulf of California in 1911. <Bulletin American Museum of Natural History, XXXV, pp. 399–476, with map and plates, August 2.

A general account of the expedition with list of places visited and a brief notice of the character of many localities and the work done there. Of special note are the location of elephant seals on Guadalupe Island and the account of the pearl oyster farm on Espiritu Santo Island.

1917. Balarezo, M. Colonización de la Baja California. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 2, pp. 110–133, Mayo.

Contains a brief summary of the physical character of the peninsula, its products, and resources, with a plan for colonization under the land system of New Zealand. Owing to obvious climatic differences between the two regions, this plan is wholly impractical.

1917. De la Vega, R. Informe sobre las Riquezas Naturales de las Islas Tres Marias. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 1, pp. 101–105, abril.

A brief report on the resources of the Tres Marias Islands off San Blas, Mexico, by the head of a commission sent by the Mexican Government for the purpose of studying them. Contains a brief résumé of the changing ownership of the islands and their exploitation.

1917. . . . . El Hispano Americano. Edicion bilingüe, Fiesta de Amistad, pp. 1–96, mapa, San Diego, Calif., junio.

This publication has the character of a periodical without serial number. The present issue is practically all devoted to short signed and unsigned articles concerning the northern district of Lower California, its resources, and its progress under the present governor, Col. Esteban Cantu. It was published to commemorate a "Friendship Fiesta" held during June, 1917, in San Diego, Calif., for the purpose of bringing people on both sides of the border into closer contact.

1917. Murphy, Robert Cushman. The Desert Life Group, and an Account of the Museum Expedition into Lower California. The Brooklyn [N. Y.] Museum Quarterly V [=IV], No. 4, pp. 179–210, with plates and cuts. October.

An interesting account of a trip into the desert northeastern part of Lower California in search of pronghorn antelope and other specimens for the fine group of desert life now installed in the Brooklyn Museum.

1917. ————. Natural History Observations from the Mexican Portion of the Colorado Desert with a Note on the Lower Californian Pronghorn and a List of the Birds. Proc. Linnaean Soc. New York, No. 29, for the year ending March 13, pp. 43–101, pl. 1, December 11.

A very full physiographic and faunal description of the valley of the Lower Colorado River, with an annotated list of 134 species of birds.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Agraria, No. 460, 12 de abril de 1917. Acuerdo de nulidad relativo al contrato de fecha 29 de junio de 1906, celebrado con el Lic. Emilio Velasco en representación de las compañias llamadas "Compañia Mexicana de Terrenos y Colonización" y "Compañia del Desarrollo de la Baja California." <Diario Oficial, Mexico, VI, No. 4, pp. 507–508, 7 de mayo; also in Periodico Oficial, Ensenada, B. C., XXX, No. 16, pp. 2–3, 10 de junio.

Cancellation of the grant for colonization of June 29, 1906, to Emilio Velasco, representing the Mexican Land and Colonization Co. and the Lower California Development Co., of the lands formerly covered by an original grant to Luis Huller y Cia, dated July 21, 1884. This grant covered most of the lands in the northwestern part of Lower California, including an area of 5,606,504 hectares.

Occupants of lands deriving titles from any of the companies named are notified that they may have their equity recognized by application to the Secretary of the Interior, Mexico.

1917. Poder Ejecutivo, Secretaría de Fomento, Colonización e Industria, Dirección Agraria, No. 455, 12 de abril de 1917. Declarando nulo el contrato de 31 de marzo de 1883, celebrado con el C. Conrado Flores para sí y para Santiago P. Hale y Ca., y al de abril de 1895 sobre deslinde y colonización de tierras en la Baja California. <Diario Oficial, Mexico, V, No. 99, pp. 483–484, 28 de abril; Boletin Oficial, de la Secretaría de Fomento, Mexico, II, No. 1, pp. 59–63, abril; also in Periodico Oficial, Ensenada, B. C., XXX, No. 17, pp. 1 and 2, 20 de junio.

Annulment of land grant of 1883 and 1895 to C. Conrado Flores and Santiago P. Hale & Co., in southern Lower California, on which was based the famous Magdalena Bay Co., of Hale, Flores & Co., and its successors, including 2,158,427 hectares of land.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Agraria, No. 648, 16 de abril de 1917. Acuerdo que declara nulo el contrato de 11 de deciembre de 1886, celebrado con el C. Pablo Macedo y traspaso a "La Mexicana" Ca. Europea para la compra-venta y colonización de terrenos en la Baja California. <Boletin Oficial de la Secretaría de Fomento, Mexico, I, No. 1, pp. 72–75, abril; also in Diario Oficial Mexico, 4 de mayo, pp. 504–505.

Annulment of grant to survey and colonize vacant lands in Lower California, from latitude 28° south to Cape San Lucas, in favor of Pablo Macedo, and conveyed by him to companies entitled "La Mexicana" and "The California (Mexico) Land Company, Limited."

1917. Poder Ejecutivo, Secretaría de Fomento, No. 468, 24 de abril de 1917. Acuerdo que declara nulo el contrato de fecha 14 de septiembre de 1888 con Ricardo Kent, a nombre de "La Mexicana" Ca. Europea de minas y terrenos en Mexico para la colonización de terrenos en la Baja California. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 1, pp. 69–72, abril; also in Diario Oficial, Mexico, 4 de mayo, pp. 503–504.

Annulment of grant dated September 14, 1888, authorizing colonization and sale of lands in Lower California by Richard Kent, for the company "La Mexicana" and, through transfer from it, by "The California (Mexico) Land Company, Limited." Occupants of lands holding titles under the grant may have their equity recognized by proper application to the Secretaría de Fomento, Mexico.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Forestal y de Caza y Pesca, 30 de abril de 1917. Contrato celebrado con los C. C. General Manuel Pérez Treviño y Coronel Juan C. Zertuche, para colonizar la Isla de Guadalupe, explotar sus productos y los de los islotes "Zapato" y "Toro," ubicados en el Océano Pacifico. <Boletin Ofícial de la Secretaría de Fomento, Mexico, II, No. 1, pp. 96–100, abril.

A contract for the colonization and exploitation of the natural products of Guadalupe Island to remain in force for 10 years from April 30, 1917.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección de Bosques, 30 de abril de 1917. Contrato celebrado entre el C. Ingeniero Pastor Rouaix, Secretario de Fomento, representando el Executivo de la Nación y el C. Juan H. Mendoza para establecer, sin derecho exclusivo, en la Baja California, dos fabricas empacadoras de productos obtenidos mediante la explotación de la pesca. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 4, pp. 359–363, julio.

Contract to establish two packing houses for fisheries products on the east and west coasts of Lower California, at a cost of at least $50,000, within two years of April 30, 1917.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Forestal y de Caza y Pesca, 31 de mayo de 1917. Convocatoría para la explotación de la Isla de Cedros. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 2, pp. 158–159, mayo.

An announcement calling for proposals for the colonization and exploitation of the resources of Cedros Island dated May 31, 1917.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección de Bosques, 28 de junio de 1917. Contrato celebrado con el C. General Fortunate Zuazua para la colonización y explotación de la Isla de "Cedros" situada en el Océano Pacifico. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 3, pp. 267–271, junio.

This contract authorizes the establishment of agricultural colonies and the exploitation of the natural resources of Cedros Island. Permission included to establish a port and install a wireless telegraph station. The concession to extend for 10 years from June 28, 1917.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección de Bosques, 3 de julio de 1917. Contrato celebrado entre el C. Ingeniero Pastor Rouaix, Secretario de Fomento, en representación del Ejecutivo de la Nación, y el C. Luis M. Calderón, para establecer, sin derecho exclusivo, en la Baja California, tres fabricas empacadoras de productos obtenidos mediante la explotación de la pesca. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 4, pp. 365–370, julio.

Permit to establish three packing houses for fish products in Lower California at a cost of at least $30,000. The permit covers a period of 10 years from July 3, 1917.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Forestal y de Caza y Pesca, 11 de agosto de 1917. Contrato celebrado con el C. Gastón Vives por la Compañia Perlífera de la Isla de San Jose, para explotar la concha-perla en dicha isla. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 5, p. 455, agosto.

An emendation of the contract granted July 5, 1893, to the Pearl Fishing Co., of San José Island, permitting the cultivation of, and fishing for, pearls and pearl shell about San Jose Island and along the coast of the peninsula from Cape Pulmo to Cape San Lucas. Dated August 11, 1917.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Forestal y de Caza y Pesca, 31 de agosto de 1917. Dispone esta Secretaría que los placeres perliferos a que se refiere el decreto de 25 de abril de 1874, asi como los que se encuentran a lo largo de las costas del Pacifico, quedan divididos para los efectos del buceo de la concha madre perla, las dos zonas o regiones que se explotarán alternativamente cada dos años. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 5, pp. 460–461, agosto.

An order that the pearl-fishing grounds on the west coast of Mexico be divided into two sections which are to be fished alternately every second year. The first zone extends from the mouth of the Colorado River to Point San Marcial on the east coast of Lower California and to the mouth of the Rio Balsas on the mainland coast of Mexico. The second zone extends from Point San Marcial to Cape San Lucas, and to the border of the United States on the west side of Lower California and from the mouth of the Rio Balsas, on the mainland, to the border of Guatemala.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Forestal y de Caza y Pesca, 6 de septiembre de 1917. Se declara insubsistente el contrato que celebró el señor licenciado Luis M. Calderon, el 3 de julio del corriente año, por no haber cumplido con el articulo 31 del referido contrato, en que deberia, en el termino de trienta dias, enterar en la Tesorería General de la Nación, $1,500, oro Nacional, para la erección de tres empacadoras y explotación de la pesca en la Baja California. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 6, p. 522, septiembre.

Cancellation on September 6, 1917, of contract dated July 3, 1917, in which Luis M. Calderon is authorized to establish three fish-packing plants in Lower California.

1917. Poder Ejecutivo, Secretaría de Fomento, Dirección Agraria, 10 de noviembre de 1917. Se declara insubsistente el contrato que celebro el C. General Fortunato Zuazua, en 28 de junio del corriente año para la colonización y explotación de la Isla de "Cedros" situada en el Océano Pacifico, y haber faltado á lo estipulado en el articulo 32 del mismo contrato. <Boletin Oficial de la Secretaría de Fomento, Mexico, II, No. 8, p. 608, noviembre.

Cancellation of grant to General Zuazua for the colonization of Cedros Island, owing to failure to comply with the terms of the contract.

1917. Singer, Dan J. Desert Trails. <Field and Stream, September, pp. 413–416; October, pp. 503–506; November, pp. 588–590; December, pp. 678–681.

A sportsman's account of a hunt for mule deer, antelope, and mountain sheep in the desert plains and in the mountain ranges of northeastern Lower California. The gray wolf is erroneously mentioned as having occurred in this region up to 1903.

1918. Secretario de Fomento, Como Estaba Dividida la Baja California. <Mercurio, I, No. 22, pp. 1–2, 16 de marzo (Seminario), Mexico.

A statement by the Secretary of the Interior, with a map showing the location of the land grants formerly held by companies and individuals covering nearly all of Lower California, but which have recently been annulled owing to their illegal character and to the failure of grantees to comply with the terms of the grants.

1919. Ashurst, Henry F. The Purchase of Lower California. <Congressional Record, vol. 57, No. 29, pp. 1148–1158, January 7.

Speech of Senator Ashurst in support of a resolution introduced by him in the United States Senate, January 2, 1919, that the President be requested to negotiate with Mexico for the purchase of Lower California, and a tract of about 10,000 acres on the northwestern border of Sonora, which would give access to the Gulf of California on its eastern shore. The resolution was referred to the Senate Committee on Foreign Relations and no further action taken. The speech contains considerable information from various sources concerning the physical character and resources of the peninsula.

1919. Dickerson, M. C. Diagnoses of Twenty-three New Species and a New Genus of Lizards from Lower California. <Bulletin American Museum of Natural History, XLI, Art. X, pp. 461–477 (New York), October 2.

The new genus *Sator* and 23 new species are described as follows: *Ctenosaura conspicuosa, C. insulana, Sauromalus interbrachialis, S. townsendi, S. varius, Callisaurus carmenensis, C. inusitatus, C. plasticus, C. splendidus, Sceloporus lineatulus, Sator angustus, S. grandævus, Uta concinna, U. mannophorus, U. parva, U. squamata, Verticaria cærulea, Cnemidophorus celeripes, C. disparilis, C. estebanensis, C. punctilinealis, C. bartolomas,* and *C. vandenburghi.*

The new reptiles described above were obtained by the *Albatross* expedition of the American Museum of Natural History and the United States Bureau of Fisheries in 1911, and are mainly from islands in the Gulf of California.

1919. Forbes, Alexander. California: A History of Upper and Lower California, from their First Discovery to the Present Time, etc. Royal 8vo, pp. xii, 372, with plates. San Francisco.

A reprint of the original published in London in 1839. It contains a general account of Lower California, its Indians, resources, and history.

1919. Funcke, E. [W.]. Hunting Antelope for Museum Specimens. <Field and Stream, March, pp. 834–836, with photographs.

A short, popular account of a hunt in northeastern Lower California made for the Brooklyn Museum of Arts and Sciences, with brief description of the desert and the birds and animals found there. This trip was more adequately described by Robert Cushman Murphy.

1919. Gordon, P. R. Filming the Sea Elephant. <The Wide World (magazine), October, pp. 485–489, with illustrations.

A popular account of an expedition to Guadalupe Island in July, 1913, to secure moving pictures of elephant seals. A second trip to the island the same season revealed the fact that sealers had raided the herd soon after the first visit by the photographers and had killed or driven away all of the animals.

1919. Townsend, Charles Haskins. Lower California. Access to the Gulf of California Versus the Acquisition of the Peninsula. <New York Times (newspaper), January 26, editorial section.

The author opposes the acquisition of the peninsula as unwise but favors the acquisition of a strip in northwestern Sonora so as to give access to the Gulf of California for commercial purposes and in order that the rich fishery resources of the gulf may become available to the interior of the United States. Some of the valuable food fishes and their abundance are mentioned.

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STUDIES UPON THE LIFE CYCLES OF THE BACTERIA.

Part I.

REVIEW OF THE LITERATURE, 1838–1918.

BY

F. LÖHNIS.

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STUDIES UPON THE LIFE CYCLES OF THE BACTERIA.

INTRODUCTION.

Results obtained in comparative studies upon the morphology and the life history of some important soil bacteria, especially of those of the Azotobacter group, made it advisable to extend these investigations, so that representatives of other prominent groups of bacteria were also included. Short reports of these investigations have been made in two preliminary communications (*Löhnis* and *Smith*, 1916 *a* and *b*), wherein it was pointed out that undoubtedly the complete life history of all bacteria is much more complicated than has been generally assumed. Our findings were summarized in the first paper (l. c., p. 700) as follows:

All bacteria studied live alternately in an organized and in an amorphous stage. The latter has been called the "symplastic" stage, because at this time the living matter, previously inclosed in the separate cells, undergoes a thorough mixing either by a complete disintegration of cell wall, as well as cell content, or by a "melting together" of the contents of many cells which leave their empty cell walls behind them. In the first case a readily stainable, in the latter case an unstainable "symplasm" is produced.

According to the different formation and quality of the symplasm the development of new individual cells from this stage follows various lines. In all cases at first "regenerative units" become visible. These increase in size, turning into "regenerative bodies," which later, either by germination or by stretching, become cells of normal shape. In some cases the regenerative bodies also return temporarily into the symplastic stage.

Besides the formation of the symplasm, another mode of interaction between the plasmatic substances in bacteria cells has been observed, consisting of the direct union of two or more individual cells. This "conjunction" seems to be of no less general occurrence than the process first mentioned. Its physiological significance remains to be studied.

All bacteria multiply not only by fission but also by the formation of "gonidia"; these usually become first regenerative bodies, or occasionally exospores. Sometimes the gonidia grow directly to full-sized cells. They, too, can enter the symplastic stage. The gonidia are either liberated by a partial or a complete dissolution of the cell wall, or they develop while still united with their mother cell. In the latter case the cell wall either remains intact or it is pierced by the growing gonidia, which become either buds or branches.

Some of the gonidia are filterable. They also produce new bacteria either directly or after having entered the symplastic stage.

The life cycle of each species of bacteria studied is composed of several subcycles showing wide morphological and physiological differences. They are connected with each other by the symplastic stage. Direct changes from one subcycle into another occur, but they are rather rare exceptions. The transformation of spore-free into spore-forming bacteria seems to be dependent on the conditions acting upon the symplasm and regenerative bodies.

The fact that all the different phases in the life history of the bacteria, i. e., conjunction, formation and development of regenerative bodies, symplastic stage, and the occurrence of different subcycles with peculiar cell morphology, were to be recorded constantly and regularly in all cases studied by us, made the conclusion inevitable that these apparently new facts must have been observed in the course of many previous investigations, though they usually have not attracted much attention, and hardly any of the bacteriological textbooks furnishes information upon them. The practical aims of most of the bacteriological investigations, together with the widespread adherence to standardized methods and theories, have been distinctly unfavorable to thorough studies along such lines. Nevertheless, at least a few references could be given in our preliminary communications, and it was to be expected that a systematic search of the literature would lead to the rediscovery of more confirmative reports, which so far had not found any acknowledgement, or which have been rejected on account of their being not in agreement with the prevalent theory. This expectation has been fully verified.

At the present time it is out of the question to make a complete collection of all such details, which are widely scattered in a gigantic literature. When in 1875 *Ferdinand Cohn* pub-

lished the second part of his "Untersuchungen über Bacterien" he was of the opinion that the literature even at that time was so voluminous that a complete survey were hardly possible even for the specialist. In 1880 *Prazmowski* made a similar remark when he reported on his "Untersuchungen über die Entwicklungsgeschichte und Fermentwirkung einiger Bakterien." Since then, every year has added thousands of new bacteriological publications. It would be an inexcusable waste of time to study all of them again in the light of the newly discovered facts. But I earnestly hope that in the discussion of the literature, as presented on the following pages, no important contribution has been overlooked, so that the general situation is presented with fair accuracy, and all those authors have been mentioned who have tried to shed more light upon the life history of the bacteria.

Complete reports upon our own experimental investigations will be given later. For making a proper arrangement of this review of the literature, however, our two preliminary communications, published in 1916, will be used. As will be seen from the following pages, every phase in the life history of the bacteria has been observed by several, sometimes even by many, independent workers, though only in comparatively few cases the complete life cycle of a distinct species has been discovered.

It seems best to arrange the whole matter in the following five chapters:

I. Different cell forms.
II. Reproductive organs. (Gonidia. Regenerative bodies. Spores. Microcysts.)
III. Formation of the symplasm and regeneration of cells.
IV. Conjunction.
V. Methods.

In chapters I and II a considerable number of details concerning the different groups of bacteria will have to be discussed. For this purpose, and in accordance with the general standpoint taken at present by most bacteriologists, the following five groups of organisms may be accepted:

(*a*) Cocci.
(*b*) Nonspore-forming rods.
(*c*) Spore-forming rods.
(*d*) Spirilla and spirochaets.
(*e*) Higher bacteria (trichobacteria, mycobacteria).

As will be seen later, this arrangement is not in accordance with the true character of and the natural relations existing among the bacteria. But as long as these facts and relations are not more completely known, it will be best to adhere to that more familiar grouping. At the end of Chapters I, II, and III some conclusions will be drawn from the observations reviewed therein, which might be helpful for further investigations. For the same reason the methods have been treated separately in Chapter V.

It is hardly necessary to point out that the data collected from the literature are of very different value, and we are often left in doubt as to their correct interpretation. Much of the material discussed on the following pages is awaiting further critical experimental study.

Special attention has been given to the morphological side of the subject. Unquestionably the physiological side is of equal or even greater importance. However, as the situation is at present, with most bacteriologists on the one side adhering to the dogma of simplicity and constancy of the form of the bacteria, while on the other side admitting a more or less considerable variability in their physiological behavior, it appears to be of prominent importance that in the first place a more correct knowledge of the morphological basis of bacteriology will be secured. As soon as the morphology of the different phases in the life cycles of the bacteria will have received adequate treatment, physiological investigations will also furnish much more satisfactory results than are obtainable now. And only after the full life history of the different types of bacteria will have been studied it will become possible to define their natural relations and to come ultimately to a correct systematic arrangement of the various species, genera, and families of the bacteria.

I. DIFFERENT CELL FORMS.

1. GENERAL DISCUSSION.

It would be preferable, if the different forms of the vegetative cells alone could be treated in this chapter, leaving to Chapter II all details concerning formation, appearance, and development of the various reproductive organs (gonidia, regenerative bodies, and spores); but this is not possible at the present time. In many cases, of course, a distinct separation is quite feasible; sometimes, however, we are left more or less in doubt whether the forms mentioned in the literature are those of vegetative or of reproductive cells. This holds true especially for many of the globular bodies. The reproductive organs, which we call gonidia and regenerative bodies, have been frequently considered to be micrococci, a mistake which indeed is quite excusable. Both of them are able to multiply as such, and as this fact is more easily to be observed than their germination, usually their real character has not been discovered. On the other hand, it does not infrequently happen that typical micrococci almost imperceptibly change from the vegetative into the reproductive state by thickening their cell wall and assuming the character of cysts, which fact, however, can be discovered only by a very close study. Other cells, too, may display either vegetative or reproductive activities without undergoing conspicuous changes in their appearance, so that their correct classification may also cause some difficulties. But even if all reproductive cells could be as clearly distinguished and separated from the vegetative cells, as is the case with the endospores, still a considerable number of trustworthy observations would remain, proving beyond doubt that, if not all, undoubtedly very many bacteria have shown themselves to be able to appear in different forms, while in the vegetative state.

(*a*) MONOMORPHISTIC AND PLEOMORPHISTIC THEORIES.

The questions concerning monomorphism or pleomorphism of the bacteria have been extensively treated by European as well as by American authors during several decades. The new point of view, which is furnished by the fact that the bacteria, like other microörganisms, exhibit different forms and activities in the various stages of their life cycles, makes it necessary to review briefly the opinions promulgated in this respect, for at least some of them may eventually become of considerable value in future researches.

In the French literature pleomorphistic ideas have been always en vogue. At first, before the theory of spontaneous generation was fought by *Pasteur*, the transformation of the "globules élémentaires," found in the residues of plant and animal life, into "infusoires" was the main point of discussion. The writings of *Dujardin* (1841), *Pineau* (1845), *Pouchet* (1863), *Trécul* (1865–1867), and *Béchamp* (1883) are to be mentioned especially in this respect. *Robin* (1871, p. 931) was inclined to consider all micrococci, bacteria, and vibriones simply as stages in the development of his *Leptothrix buccalis*. *Davaine* (1876), however, correctly emphasized, as had been already done by *Dujardin*, that undoubtedly many different species exist; bacterium and vibrio are declared to be related to Leptothrix, but not to be identical with it. When studying a distinct species, it is said to be of special importance to pay attention to the variability of its forms "qui changent suivant diverses conditions." *Duclaux* (1883) wrote in his "Chimie biologique" (p. 33):

> En résumé, toute classification fondée sur des caractères purement morphologiques semble impossible . . . Pour donner une idée de l'incertitude qui en resulte, je dirai que la qualification de Bacillus subtilis a été donnée déjà a une dizaine d'êtres, tous identiques si on ne consulte que leur nom, tous différents si on ne consulte que les propriétés qui leur sont attribuées dans les divers mémoires qui en parlent.

The following statement, made by *Artigalas* (1885, p. 23), forecasts our present standpoint with remarkable accuracy:

Nous verrons qu'un microbe donné peut, à une certaine période de son évolution, être rapporté à un type dont il se sépare complètement dans la suite. En un môt, un microbe peut passer par des transformations telles que, comparé à lui-même, l'expérimentation seule en puisse démontrer l'identité.

Correcting an erroneous view and tendency, which was rather common at that time and later in the German as well as in the American literature, *Guignard* and *Charrin* wrote, reporting on their interesting experiments "Sur les variations morphologiques des microbes" (1887):

Ce polymorphisme . . . n'ébranle en rien la notion généralement admise pour l'espèce; il n'en doit pas moins attirer de plus en plus l'attention sur l'influence des milieux . . . et mettre en garde contre certaines tendances à trop multiplier les espèces en se fondant sur des données morphologiques, insuffisantes.

More evidence against the assumed constancy of form and function was furnished by *Wasserzug's* publications (1888 *a* and *b*). *Metchnikoff*, too, in various contributions (1889–1894), dwelt upon the "pléomorphisme, si répandu dans le monde des bactéries."

In the third edition (1890) of "Les bactéries et leur rôle dans l'étiologie, l'anatomie et l'histologie pathologique des maladies infectieuses" *Cornil* and *Babes* defined their standpoint as follows (Vol. I, pp. 18 and 30):

Un grand nombre de botanistes affirment que les bactéries présentent des formes diverses suivant le degré de leur développement et le milieu nutritif où elles sont placées. Cette polymorphie est bien démontrée pour un grand nombre d'entre elles . . . On doit même se demander si toutes les bactéries ne présentent pas des formes variées et si l'on ne décrit pas aujourd'hui un même microbe sous plusieurs noms différents.—Il ne faudrait pas croire que les formes des bactéries soient toujours constantes, immuables, de façon à caractériser des genres distincts. Tout au contraire, on sait que certains micro-organismes revêtent des formes diverses pendant leur développement de telle sorte qu'ils se présentent comme un coccus, un bâtonnet, un filament ou une spirale dans les états successifs de leur accroissement.

Similar to *Artigalas*, *Billet* (1890) emphasizes the necessity of investigating the complete life-history of the bacteria, because, as he says (p. 217):

On reconnaîtra peut-être alors qu'un grand nombre des formes que l'on décrites jusqu'ici comme des espèces absolument distinctes étrangères l'une à l'autre, ne sont, en réalité, que des formes d'éléments appartenant à la même espèce.

When *Rodet* in 1894 published his book entitled "La variabilité dans les microbes," *Arloing*, who wrote the preface for it, made the following reference to the dogmatism of *R. Koch* and his pupils:

Il fut un temps où l'on croyait qu'un microbe avait des fonctions immuables comme sa forme . . . Les microbes étaient donc specifiquement et rigoureusement determinés par la forme et les propriétés. Cela était un dogme sur lequel semblait reposer toute la microbie. Un novateur ne pouvait le menacer sans soulever des protestations ou faire naître un sentiment de défiance a l'égard de ses travaux.

Further proof supporting the pleomorphistic view was also furnished by *Arloing* himself in cooperation with *Chantre* (1894).

Macé (1897) is the only French author who has sometimes been quoted as standing on the monomorphistic side. He is, indeed, of the opinion that much of what has been found by other French bacteriologists in their investigations upon the variability of the bacteria has been obtained under special, distinctly abnormal conditions (p. 13). But he also writes, very similar to *Cornil* and *Babes*, concerning the one-sided theory held at that time by most of the German bacteriologists (p. 12):

Cette opinion a été fortement battue en brèche, lorsqu'on est arrivé à prouver que certaines espèces pouvaient, selon les circonstances de milieu ou la phase de leur cycle évolutif, donner tantôt des cellules sphériques, des Coccus, tantôt des bâtonnets courts, tantôts des filaments droits, tantôt des filaments spirales.

The same more or less pleomorphistic standpoint is also taken in the more recent French publications, e. g., in the textbooks of *Miquel* and *Cambier* (1902), *Burnet* (1911), who even says (p. 66): "Les bactéries sont variables au point de dérouter les bactériologistes;" *Le Blaye* and *Guggenheim* (1914), and *Kayser* (1914). The latter once more clearly emphasizes the point which in the German, as well as in the American, literature has caused much misunderstanding (p. 28):

Cette grande variété de formes n'est nullement en contradiction avec l'unité de l'espèce.

In the British bacteriological literature the pleomorphistic point of view is not quite so generally accepted as was the case in France. *Huxley* (1870), who unfortunately believed in the accuracy of the work done by *Hallier* and *Lüders* in Germany, thought that really Penicillium could produce Torula and this bacteria, a hypothesis which was at once refuted by *Burdon-Sanderson* (1871). *Bastian*, on the other hand, became a persistent advocate (1872–1914) of the theory of heterogenesis as it was upheld by the earlier French writers (*Pineau, Pouchet, Trécul, Béchamp*). Distinctly pleomorphistic ideas were also promoted by *Lister* (1873) and by *Lankester* (1873–1876). *Lister* himself modified his statements later (1878) as far as they were based on incorrect conclusions drawn from results obtained with mixed cultures. But he was right when he said (1873) that a classification of the bacteria based upon absolute morphological constancy "is entirely untrustworthy;" and his clear drawings of branching and budding bacteria also deserve our interest to-day. *Lankester*, too, undoubtedly worked with impure cultures, but it must not be overlooked that much of his work is based on continuous microscopic observations of the changes in morphology exhibited by his *Bacterium rubescens*. And at least in some cases it still can be shown, as will be done in Chapter III, that in fact his observations have been much more accurate than those of his critics.

A distinctly monomorphistic standpoint was taken by *E. Klein* (1885) in his textbook on "Microörganisms and Disease," obviously under German influence. He points out that true micrococci never elongate to form rods, and mentions as such "true micrococci" *F. Cohn's* "*Micrococcus*" *prodigiosus* and *violaceus*, which he also found to be always globular and immotile, contrary to now well-known facts. But his own observations on anthrax, cholera, and other pathogenic organisms equally militated against his standpoint. And some years later, after he had found that *Bacillus anthracis* sometimes assumes a morphological character which resembles very much that of some Saccharomyces or Oidium, he even did not hesitate to say (1894): "Probably it returns to an atavistic stage in its evolutional history."

H. M. Ward (1887) clearly states that "Schizomycetes are pleomorphic," but, as he adds, this is "no reason to deny the existence of distinct species." *Woodhead* (1891), on the other hand, is of the opinion that the doctrine of pleomorphism "can not be accepted as in any way proved except in the case of a few well-known nonpathogenic forms," whereas, according to *Crookshank* (1896, p. 478), this doctrine is "widely accepted" and—

> Researches by competent observers have more recently clearly demonstrated that several microörganisms in their life cycle exhibit successfully the shapes characteristic to the orders of Cohn. . . . These facts obviously shake the very foundation of *Cohn's* classification, and we are left without possessing a sound basis for classification into genera and species.

Hewlett (1902) writes that "a certain amount of pleomorphism undoubtedly occurs in some organisms," and *Muir* and *Ritchie* (1903) equally admit that "there are cases where evidence appears to exist of the occurrence of pleomorphism."

Harris (1893) found that one of two aerobic organisms isolated from oedema was able to exhibit "a complete series from cocci to bacilli." The other, too, was "remarkable for its pleomorphism." *Durham* (1898) studied closely the dimorphism of Micrococcus melitensis. *Adami* (1892–1899) furnished other important contributions concerning the variability of the bacteria. Together with *M. E. Abbott* and *Nicholson* (1899) he was able to show that especially *B. coli* may grow as a minute coccus, which also differs entirely in its cultural character from the typical form. Another report upon these investigations, to which we have to refer later, was published by *M. E. Abbott* (1900).

Dobell (1911, p. 484) believes "that the greater number of bacteria are pleomorphic," and he continues:

> The bacteria are in no way a group of simple organisms, but rather a group displaying a high degree of morphological differentiation coupled in many cases with a life cycle of considerable complexity.

Revis (1912 *a*) changed a Coli strain experimentally to such an extent "that it now was neither physiologically, morphologically nor culturally a Colon bacillus." *Rowland* (1912) succeeded in imposing all marks of *B. pseudotuberculosis rodentium* upon a typical strain of *B. pestis*. And results secured with many kinds of organisms, led *Young* (1914) to the hypothesis

"that all bacteria formed merely stages in the life history of a group of organisms with an extremely complicated life cycle."

The most important contributions to our subject, however, in modern British literature are those of *Hort* (1915–1917) and his collaborators, to which we will have to refer frequently. It was with good reason that *Adami* (1916), after having become acquainted with these new observations, raised the question:

> Have we all these decades been wrong in our faith, that bacteria are the simplest of all living forms of life, possessed of asexual multiplication by fission only? May there not be intercalated other phases in the life history of the schizomycetes?

The German and Austrian bacteriological literature shows an interesting change from monomorphistic to extremely pleomorphistic views, then back to the rigorously monomorphistic standpoint of *R. Koch* and his pupils, and at last an almost general acceptance of the moderate pleomorphism as it has always been taught by French bacteriologists.

Although there is no special discussion upon this problem, the monomorphistic point of view is already clearly discernible in *Ehrenberg's* (1838) as well as in *F. Cohn's* (1853) early publications. It is, however, by no means, that strict monomorphism which was advocated 20 years later by the same author. *Bact. termo*, e. g., was declared to be able to grow in globular, curved, or rodlike form.

The extreme pleomorphism, on the other hand, promulgated especially by *Hallier* (1865–1878) and by *Lüders* (1866), undoubtedly was not supported by sufficiently reliable observations, but it can also not be considered fair to condemn summarily all what has been written by *Hallier* as being "scientific nonsense" (*Winter*, p. 33), or as merely belonging to the scientific "chronique scandaleuse" (*DeBary*, p. 137). As much of this work was based on long continued direct microscopic studies, some of his results, though obtained with impure cultures, still retain their value, and will even regain new interest in connection with other data which are to be discussed in Chapter II. The same holds true in respect to various facts observed by *Karsten* (1869). This author, as well as *H. Hoffmann*, already in 1869 and with good reason rejected *Hallier's* erroneous assumption of a direct connection existing between fungi and bacteria. *Hoffmann's* publication is of special interest, because it contains the first drawings of branched bacteria, which later were rejected by the extreme monomorphists.

Morphological changes of single bacteria cells have been studied directly under the microscope by *Rindfleisch* (1872), as well as by *Billroth* (1874). The latter author has been repeatedly called the champion of the older pleomorphism, usually on account of no other reason than that he named all bacteria together *Coccobacteria septica*. But he left it explicitly (p. 35) for the botanists to decide, whether or not the different forms which he observed were merely different types of growth of this one *Coccobacteria septica* or whether several genera and species should be made.

It is a similar case with *Nägeli's* standpoint. Usually the following sentence (1877, p. 20) has been quoted as convincing proof of his alleged error:

> Ich habe seit zehn Jahren wohl tausende von verschiedenen Spaltpilzformen untersucht, und ich könnte (wenn ich Sarcina ausschliesse) nicht behaupten, dass auch nur zur Trennung in zwei specifisch verschiedene Formen Nöthigung vorhanden sei.

However, the following statement in the same publication (1877, p. 22) also must be taken under consideration:

> Wenn ich sage, dass die uns bekannten morphologischen Eigenschaften der Spaltpilze und ihr Vermögen, verschiedene Zersetzungen zu bewirken, eine generische und specifische Unterscheidung nicht rechtfertigen, und dass selbst die Möglichkeit vorliege, alle Formen in eine einzige Species zu vereinigen, so liegt es mir doch fern, diese Behauptung wirklich auszusprechen. In einer Sache, in welcher die morphologische Beobachtung und der physiologische Versuch den Forscher noch so sehr im Stiche lassen, ist es überhaupt gewagt, eine bestimmte Ansicht auszusprechen.

In his later work (1882, p. 130) he defends himself against those who assert that he be inclined to consider all bacteria one species. But at the same time he points out that also according to his new experiments with pure cultures, all morphological and physiological qualities of

the bacteria may vary to a considerable extent. His standpoint is best defined by the following quotation (p. 138):

Es wird bei den Spaltpilzformen die nämliche Erfahrung sich wiederholen, die in neurer Zeit an den übrigen Pilzen gemacht wurde, wo die verschiedenartigsten morphologischen und physiologischen Erscheinungen als verschiedene Generationen einer und derselben Species erkannt wurden. Die Species wird nicht durch absolute Merkmale kenntlich sein, sondern dadurch, dass sie unter bestimmten äusseren Umständen bestimmte Modificationen des morphologischen und physiologischen Verhaltens, unter anderen Umständen andere Modificationen zeigt. Ein System der Spaltpilze nach Gattungen und Arten mit den jetzigen Hilfsmitteln aufzustellen hat keinen wissenschaftlichen Wert.

That, in fact, bacilli may assume sometimes distinctly coccoid shape, and spirilla may temporarily look like straight rods, *Nägeli* was able to ascertain with pure cultures. Some years earlier *Klebs* (1875 *b*) had made a similar statement, also based on direct microscopic observations.

When *Ferdinand Cohn* began the publication of his "Untersuchungen über Bacterien" (1872), he also, by no means, advocated those extreme monomorphistic ideas, which later, mostly on account of the writings of his followers, have been attributed to him. He strongly emphasized that genera, as well as species, proposed by him were to be considered form genera and form species, not natural ones. The following lines (1872 *b*, p. 130) clearly define his original standpoint:

Wir sind genötigt, bei den Bacterien in vielen Fällen ein Verfahren anzuwenden, das auch in der Mycologie so lange festgehalten wird, als nicht durch vervollkommnete Culturmethoden die gesamte Entwicklungsgeschichte der Arten festgestellt werden kann. . . . Es besteht darin, dass jede Form, die sich durch hervorstechende Merkmale auszeichnet, mit einem besonderen Gattungsnamen belegt wird; jede kleinere Abweichung wird als Species unterschieden. Es soll damit nicht die Möglichkeit ausgeschlossen werden, dass nicht verschiedene solcher Species aus einer und derselben Mutterform hervorgehen, ja dass nicht selbst verschiedene Gattungen nur Entwicklungszustände eines und desselben Individuums sein können.

In his later contributions (1875, p. 142; 1876, p. 274) *Cohn* changed his mind in so far as he now declared his genera to be natural, not only form genera. His own investigations, however, did not support this statement. There was indeed no possibility at that time to study the complete life history of these smallest organisms, and *Cohn's* classification is clearly incorrect in many cases. E. g., he mentions in his "natural" genus Micrococcus, which is said (1872 *b*, p. 151) to be made up of immotile globular or oval cells, the following species:

Micr. prodigiosus, luteus, aurantiacus, chlorinus, cyaneus, violaceus, ureae, candidus, vaccinae, diphteriticus, septicus, bombycis, fulvus, phosphoreus.

According to our present knowledge only 5 of these 14 species (*M. luteus, aurantiacus, cyaneus, ureae,* and *candidus*) are really Micrococci. That such conspicuous characters as the motility of *B. prodigiosus* or the pleomorphous nature of *Myxococcus fulvus—Jahn* (1909–1911, pp. 191 and 198) has shown that this, indeed, is what *Cohn* called *Microc. fulvus*—have not been noticed by *F. Cohn* sufficiently proves our point.

The German botanists who, like *Winter* (1884) and *Schroeter* (1886), otherwise closely adhered to *Cohn*, did not accept his genera as "natural" ones. *Winter* (p. 36) says that several of *Cohn's* genera are merely developmental stages of other genera and that many of his species probably are nothing else than more or less constant modifications, split up from one species under different environmental conditions. *Schroeter*, too, was of the opinion (p. 140) that the form of the individual cells very often change in the course of their development. They all must be known before the true character of a species can be defined.

As *Robert Koch* in the early part of his bacteriological work was greatly influenced by *F. Cohn* just at the time when this author had left his earlier, more cautious standpoint, naturally the monomorphistic view was readily adopted. In his "Untersuchungen über die Aetiologie der Wundkrankheiten" (1878) the following statement is made (English translation, p. 71):

In all my experiments not only have the form and size of the bacteria been constant, but the greatest uniformity in their action on the animal organism has been observed.

Constancy of form and action became a dogma, which was upheld for the next decades more by *R. Koch's* pupils than by himself. That in many cases constancy of action is missing

was soon shown by French bacteriologists under the leadership of *Pasteur*. And the question whether or not separate species should and can be based on the frequently very small differences found has been left unanswered by *R. Koch*. On account of practical reasons he emphasized the necessity of making as many divisions as were indicated by differences of form or action. But he did not care whether these now might represent "species, or varieties, or forms, or what else one should like to call them" (1881, p. 31). And later he was even quite willing to admit the variability of the bacteria (1890):

Innerhalb gewisser Grenzen können Abweichungen von dem gewöhnlichen Typus der Art bei den Bakterien und insbesondere auch bei den pathogenen Bakterien vorkommen.

Strictest constancy of form and action was first proclaimed by *Gaffky* (1881). To him it was unquestionable that any change which might occur was caused by the overgrowing of one species by another. Though *Friedländer* (1883) found that his "Mikrokokken der Pneumonie" (now usually called *B. pneumoniae*) can grow either in distinctly globular, oval, or in rod-like form of different length, *Flügge* (1884) did not hesitate to declare:

Niemals haben wir beobachten können, dass wirkliche Cokken in Bacillen sich umwandeln und umgekehrt.

In the same publication this author makes also another characteristic statement which later has caused much unnecessary confusion:

Wenn Thatsachen gefunden wären, aus welchen die Wandelbarkeit der Infectionserreger gefolgert werden müsste, so würden wir . . . . auf eine weitere experimentelle Erforschung der Infectionskrankheiten verzichten müssen.

Buchner (1885), however, correctly pointed out that the disputed constancy of form and action has nothing whatever to do with the indisputed constancy of species. Nevertheless, this logical mistake is even to-day not yet quite eliminated.

The "Bacteriologische Diagnostik," published by *J. Eisenberg* in 1890, gives a very characteristic picture of the German literature as it was written at that time by *R. Koch's* pupils. Even such highly pleomorphous organisms like the diphtheria and tubercle bacilli were considered to be correctly described as follows:

Diphtheria bacillus (p.237): "Teils gerade, teils leicht gebogene Stäbchen von der Länge der Tuberkelbacillen, jedoch etwa doppelt so dick. In gefärbten Präparaten durch überwiegende Farbstoffaufnahme an den Enden hantelförmig."

Tubercle bacillus (p. 253): "Sehr dünne, 2–5μ lange Stäbchen, meist leicht gekrümmt."

The following two statements of *C. Fränkel* (1891, pp. 12 and 169) are equally interesting. The constancy of action is not longer upheld, but *Flügge's* logical mistake is renewed:

Bisher ist eine vielförmige Bakterienart nicht zur Beobachtung gelangt, und der Satz "Man kann unter den Bakterien nach Wirkung und Form scharf unterschiedene Gattungen und Arten erkennen, welche nicht in einander übergehen" bleibt zu Recht bestehen.—Freilich ist die Grenze, die wir zwischen pathogenen und nicht pathogenen Bakterien ziehen, keineswegs eine feste und unverrückbare. Eine ganze Anzahl von Mikroorganismen, die gewöhnlich ganz harmlosen Character zeigen, vermögen unter Umständen auch eine pathogene Rolle zu spielen, und ebenso kann manche pathogene Art ihre gewöhnlichen Eigenschaften ablegen und in die Reihe der unschädlichen Bakterien übertreten.

Gotschlich (1903–1909) and *Günther* (1906) once more tried to support the "morphologische Grundgesetz" of the constancy of the form as proclaimed by *Cohn* and *Koch*, though a considerable number of contradictory results now had to be admitted. *Günther* accepts already for the different species not a constant form, but a constant form cycle. But he still thinks the constancy of the form is indisputable, because there is no "unlimited" morphological variability (1906, p. 22).

Among the German botanists the monomorphistic theory also gained some temporary foothold.

When *Brefeld* in 1881 first entered the subject, he wrote quite correctly, similar to *Nägeli* (p 50):

Die Untersuchung von Spaltpizformen muss . . . entwicklungsgeschichtlich . . . in Angriff genommen werden, wenn eine natürliche Systematik . . . begründet werden soll. Die vorläufigen Einzelheiten reichen dafür auch nicht von ferne aus.

Later, however, his standpoint was quite different (1908, pp. 99–100):

In rein morphologischer Beziehung bieten die Bakterien nach ihrer einfachen Formbildung und der stereotypen Art ihrer Teilung und Vermehrung wenig Bemerkenswertes dar . . . Die Ziele der Kultur bei den Fadenpilzen,

die Höhe der vegetativen Bildung zu erreichen und dann die verschiedenen Fruchtformen auf dem Wege der Kultur aus den vegetativen Zuständen zu gewinnen, ihre Zusammengehörigkeit zu den einzelnen Formen der höheren Pilze sicher festzustellen, liegt bei den Bakterien von vornherein ausserhalb der Fragestellung.

A. Fischer (1903, p. 44), as well as *A. Meyer* (1912, p. 61), take also their stand against the pleomorphism, though, of course, they do not dispute the variability of the cell form. *Benecke* (1912, p. 216) says:

Jede Art hat ihren Variabilitätskreis, der grösser oder kleiner sein kann.

The very numerous papers on variation, mutation, etc., contained in the German literature of the last decade, will have to be discussed later. Taken together, they furnish convincing proof that the monomorphistic theory of *Cohn* and *Koch* has become utterly untenable.

However, more or less opposition has always been put forward by other German and Austrian bacteriologists, though the very important practical results attained by *R. Koch* and his pupils have materially helped to keep their antagonists temporarily in the background.

Neelsen (1880) drew the following conclusion from his studies upon *B. cyanogenes*, which are of special interest because this work was done in *F. Cohn's* laboratory and published as the tenth contribution to his "Untersuchungen über Bacterien." It is stated therein (p. 242):

dass die von *Cohn* aufgestellten Gattungen insofern zu eng begrenzt sind, als ein Organismus in seinem Lebenscyclus verschiedene der als getrennt hingestellten Formen vereinigen kann.

Haberkorn (1882) emphasized correctly that the hypothesis of simplicity and constancy of form was not well founded. Unfortunately his own experiments, though very interesting, are open to the same criticism. But he was right when he wrote:

Richtiger, d. h. der Wissenschaft förderlicher ist, beim Forschen noch Lücken im Entwicklungsgange vorauszusetzen, als voreilig den genetischen Cyclus abzuschliessen.

Miller's (1882) investigations upon the bacteria of the human mouth, *Kurth's* (1883) isolation of *Bacterium Zopfii*, growing in globular, rod-like and spiral form, *Hauser's* (1885) discovery of his three Proteus forms, first considered to be different species, later (*Hauser*, 1892) acknowledged as modifications of one species, *Biedert's* (1885) and *Malapert-Neufville's* (1886) studies upon other pleomorphic bacteria from mouth and water, furnished additional proof that pleomorphism does by no means obscure, but even enhances the well defined character of a species. *DeBary* (1884) also declared, that doubtless different species have to be distinguished with the bacteria as with the higher organisms. Some of them may exhibit a relatively monomorphous character, while others may be distinctly pleomorphic.

The most prominent place among the German adversaries of *Cohn's* and *Koch's* standpoint has been taken by *Zopf* (1881–1885). It is true that many of his ideas have been gathered from studies done with species (especially with thread-bacteria) which have not very much in common with the pathogenic microbes *Koch* was interested in. Nevertheless, his opposition against the extreme monomorphism was sufficiently supported by well ascertained facts, and he was equally right when he emphasized, like *Nägeli* and *Buchner*, that as long as the complete life history of the bacteria remained unknown no correct systematic arrangement could be made.

More well-founded criticism concerning the alleged constancy of form was furnished by *Gruber* (1885, 1894), *Firtsch* (1888), and *Escherich* (1886). The last-named author says, that now, after *Koch's* methods have made it possible to study rigorously pure cultures, more and more bacteriologists are inclined to accept the pleomorphistic point of view.

Rosenbach's publications on the causative agent of the so-called erysipeloid exemplify in a very interesting manner how extended research may completely change the situation. In 1884 he described the organism as a *Micrococcus;* in 1887 he declared it to be a peculiar branching organism probably related to *Cladothrix* (Streptothrix), and in 1909 he showed that it represented a variety of *Bact. erysipelatos suum*, of which he discovered the full very polymorphous life cycle.

The following quotations from *Hueppe's* writings are equally interesting. In 1883 he criticized *Zopf's* standpoint in a very sharp manner, very much like *Flügge* (1884). No change from a coccus to a bacillus or vice versa could be accepted, and the idea that the tubercle bacillus might be related to any "thrix" was declared to be entirely absurd. Ten years later *F. Fischel*

(1893) secured conclusive proof for this relationship by his investigations carried out under *Hueppe's* direction. But already in 1886 *Hueppe's* own standpoint had undergone considerable modification. The "dogmatic onesidedness" (p. 85), which knows nothing but strict constancy of form or unlimited variability, was now refuted and it was said (p.61):

Wenn auch die einzelnen Formen sich bald mehr bald weniger mit den Aussenbedingungen ändern können . . so tritt doch unter denselben Verhältnissen immer ein ziemlich scharf bestimmter, bald enger, bald weiter Formenkreis auf.

In 1891 (pp. 22, 27) the occurrence of all different cell forms within the life cycle of the same organism was still more readily admitted by *Hueppe*. And in 1896 *Zopf's* standpoint has been practically reached (p. 15):

Die starren Formarten, wie sie . . . *Cohn*, *Schroeter*, und *Koch* angenommen hatten, haben sich nicht aufrecht erhalten lassen. Die Anpassungsfähigkeit der Bakterienformen bei Wechsel der Ernährungsbedingungen ist . . . beträchtlich grösser, als man früher mit dem Begriffe konstanter Arten für vereinbar gehalten hatte.

Migula was at first also very much opposed against all "pleomorphistischen Gelüste' (1897, Vol. I, p. 18). He taught (l. c., p. 50):

Die Bakterien zeigen eine grosse Einförmigkeit. Drei Gestalten sind es, welche uns immer wieder bei ihnen entgegentreten: die Kugel, das cylindrische und das schraubig gekrümmte Stäbchen.

But in the same book (p. 236) he also wrote:

Inwieweit die einzelnen Arten verschiedene Formen zu bilden vermögen, muss der weiteren Forschung vorbehalten bleiben; unsere gegenwärtige Kenntnis davon ist im höchsten Grade lückenhaft.

In 1904 he admitted in *Lafar's* "Handbuch" (Vol. I, p. 42) that the monomorphistic theory had to be abandoned. The same statement had been made by *Lafar* himself in 1897 (p. 36), and since then it has been amply confirmed by the results of practically all investigations made along these lines by German and Austrian bacteriologists. The present situation is correctly described in the following quotation from *Lehmann* and *Neumann* (1912, pp. 146–149):

Die Cohnsche Lehre von der Konstanz der Arten . . . wird heute in immer weiterem Umfange unhaltbar. Denn die fortgesetzte, immer tiefer gehende Forschung hat zur Evidenz erwiesen, dass fast alle Eigenschaften einer wohlumgrenzten Art sehr schwanken. . . . Wir glauben sicher, dass es der Zukunft noch in heute kaum geahnter Weise gelingen wird, Bakterienarten in einander überzuführen. . . . Die Lehre von der absoluten Unveränderlichkeit der Bakterien, die vor 20 Jahren noch fast als Dogma galt, wird heute kaum mehr ernsthaft vertreten.

The old extreme pleomorphism of *Hallier* has been also revived in the German literature from time to time. *Hallier* himself reiterated his former statements in 1895 and 1896, which he now thought to be "in complete agreement with *R. Koch's* discoveries." *J. Müller* published a similar work in 1898. To him the bacteria are still the offspring of the spermata of different fungi, though already in 1869 *H. Hoffmann* had proven that this is not the case. Equally erroneous were the discoveries of *Stutzer* and *Hartleb* (1897) concerning their highly pleomorphic "Salpeterpilz" (a complex mixture of various fungi and bacteria, as was shown in 1898 by *Gaertner*, *Fraenkel*, and *Krueger*) and their "Bakterium der Maul- und Klauenseuche." *Niessen's* "Syphilomyces" (1908) belongs in the same class. *Dunbar's* book "Zur Frage der Stellung der Bakterien, Hefen und Schimmelpilze im System" (1907), which apparently confirmed many of the old statements of *Trécul*, *Béchamp*, *Bastian*, *Hallier*, and others, elicited the following characteristic remark from *Pringsheim* (1910, p. 139):

Bei solchen Behauptungen fasst man sich an den Kopf, um sich zu versichern, dass er noch auf den Schultern sitzt. Das ganze Gebäude unserer Wissenschaft droht zusammenzustürzen.

As I will have to show in Chapter II, the knowledge of the formation and development of the bacterial gonidia helps to make these so far unexplainable observations quite intelligible.

The standpoint taken by the bacteriologists in other European countries is mostly on the pleomorphistic side.

In Switzerland *Perty* (1852) has furnished one of the earliest contributions to the knowledge of the life history of the bacteria, especially concerning their upgrowth from the gonidial stage. More recently *Düggeli* (1905) discussed the question of the systematic arrangement of the bacteria, closely agreeing with *Lehmann* and *Neumann*.

In Italy the view, once held by *Robin*, that the different cocci and rods merely represent stages in the development of *Leptothrix buccalis* was renewed by *Vincentini* (1893), to whom pneumococci and tubercle bacilli were only types of growth of a *Leptothrix racemosa*. In Naples

Schroen made several important investigations, to which we will have to refer later. This also will be the case with the work done by *Ferrán* in Spain.

Gedoelst (1899) in Belgium shared the standpoint taken by his French colleagues. *Fokker* in Holland took his place at the side of *Trécul* and *Béchamp*. He was one of the earliest opponents (1882) of the constancy dogma of *Cohn* and *Koch*. Recently *E. de Negri* in Utrecht discovered the complete life cycle of the Corynebacteria (1916).

In Denmark the work done by *Lankester* in England was confirmed by *Warming*, who concluded (1876, p. 10):

> Les bactéries sont données en réalité d'une plasticité illimitée, et je crois qu'il faudra renoncer au système de M. Cohn et de quelques autres savants, qui caracterisent les genres et les espèces d'après leur forme.

E. Chr. Hansen in Copenhagen discovered the pleomorphism of the acetic acid bacteria. *Schmidt* and *Weis* (1902, p. 78) also discussed the inconstancy of the cell form. *Jörgensen* (1911) wrote in his textbook (English translation, p. 78):

> A single species of bacteria may occur in various forms, and this may happen either during the normal growth of the vegetation, or in growths on different media.

In Norway the strictly monomorphistic side was represented by *G. A. Hansen*. As late as in 1903 he still rejected as unreliable all reports on irregular, especially on branched forms of tubercle and leprosy organisms. On the other hand, *Olsen* (1897) has furnished very interesting data supporting the pleomorphistic point of view. In his opinion, probably all bacteria, at least all bacilli, are able to exhibit under favorable conditions a branched, mycelial growth.

Still more important contributions have been made by *Almquist* and his pupils in Sweden. He is one of the few authors, who discovered independently the complete life cycles of different pathogenic bacteria. Much valuable material is contained in a long series of his publications (1893–1917).

In Russia as early as 1877 *Cienkowski* has proved convincingly that *Cohn's* form genera were untenable. *Winogradsky*, on the other side, strongly defended in his early papers (1887–1889) the strictest monomorphism against *Lankester*, *Warming*, *Zopf*, *Metchnikoff*, and others, though he admits that further experimenting perhaps might change the situation. In fact, his own nvestigations upon the nitrite bacteria (1892) did not support his monomorphistic standpoint. Within the same species the cell forms varied to such an extent that, as he says—

> On croiraît sûrement avoir affaire à des organismes différents. Il n'en est pourtant rien.

In America at first the French standpoint won some influence by *G. M. Sternberg's* edition of *Magnin's* textbook (1884). Later, however, following *Baumgarten* (1890) the bacteria were divided by *Sternberg* (1896) into two groups: I. Relatively monomorphous; II. Pleomorphous organisms. *H. L. Russell* (1892) found among marine bacteria considerable morphological variation. *Th. Smith* (1890–1900) studied the various factors modifying the development of different pathogenic organisms and took his stand against the reckless "species" making. *Hopkins* (1898) isolated apparently the same pleomorphous mouth bacterium which had been studied in Germany by *Biedert* (1885). Although it clearly grows either in globular or in rod-like form according to the environment, the author emphasizes that "it is not positively asserted that a rod can be produced from a coccus, nor a coccus from a rod." *H. W. Conn* (1900) made some interesting observations upon the wide physiological variability in pure cultures of micrococci. *N. G. Davis* (1901) got a typical coccus from *Bac. rosaceus metalloides*. *Ohlmacher* (1902) isolated from a colon septicaemia a colon bacillus exhibiting a "truly astonishing" pleomorphism. The task of making a detailed description of all the various shapes assumed by this bacillus, he declares "well-nigh impossible."

In spite of these and other contributions of American bacteriologists, there are, however, only comparatively few American textbooks which do not adhere to the rigid monomorphism which had been taught in Germany.

The inconstancy of form and action has been advocated by *Chester* (1901), to whom (p. 51) "one form appears to merge into another," and by *E. F. Smith* (1905), who says (p. 177):

> We know that bacteria are much more responsive to changed environment than was supposed by *Koch* and his followers in the eighties, and we are prepared to believe anything respecting their origin and their polymorphism which can gain the suffrage of the great body of critical workers who now cultivate this field.

On the other hand, *A. C. Abbott*, (1902, p. 51) emphasizes:

One can never produce bacilli from micrococci, nor vice versa; and any evidence which may be presented to the contrary, is based upon untrustworthy methods of observation.

Like to *Cohn*, *Koch*, and their followers, to *Ball* (1908), as well as to *Frost* and *McCampbell* (1910), a change in cell morphology is synonymous to a change of species or genus. Accordingly, statements like these are made:

A bacillus does not arise from a micrococcus or the typhoid fever bacillus produce the bacillus of tetanus.—(*Ball*, p. 23.)

It is not possible to cause any permant change in the morphology of a bacterium and thus originate a new species of bacteria. For example, it is not possible to cause a bacillus to change into a coccus and vice versa.—(*Frost* and *McCampbell*, p. 25.)

Though not quite in such dogmatic terms, constancy of form is also advocated by *Jordan* (1909, p. 54; 1916, p. 65):

Under normal and uniform conditions of life each form breeds true, the spherical forms producing only spheres and the rods, again, only rods.

Concerning the plague bacillus, however, it is said (1916, p. 321):

Many morphologic variations, coccus shapes and large rods, are found.

The standpoint taken by *Park* and *Williams* (1914 p. 31) is similar:

Micrococci always, under suitable conditions, produce micrococci, bacilli produce bacilli, and spirilla produce spirilla.

Nevertheless, the variability of the cell form is more adequately discussed in this work. Of special interest is a picture (p. 294, fig. 119) showing a variety of diphtheria bacilli which grows exclusively in the form of a large coccus.

Hiss and *Zinsser* (1914, p. 19) say:

Variations from the basic forms may occur, but are not common among bacteria under normal conditions.

Kendall (1916, p. 21) repeats the statement made by *Jordan* and adds (p. 23):

Given constant conditions, bacteria growing in a favorable environment exhibit constancy of form and size, although a few organisms in every culture are somewhat larger or smaller than their fellows, appearing as occasional giants or dwarfs.

Pleomorphism is said (p. 24) to be "rarely or never met with among the pathogenic bacteria." However, the diptheria bacillus is declared (p. 389) to be "highly pleiomorphic" and the plague bacillus (p. 408) "very pleiomorphic."

In recent American literature generally the interest has been centered more upon physiological than morphological problems. *Orla Jensen's* so-called natural system of the bacteria, almost entirely based on mere biochemical hypothesis, has been accepted, for instance, by *Jordan* (1916 p. 197) as "a promising beginning in classifying bacteria." Accordingly, morphological questions are not infrequently left without adequate consideration. When describing the characters of the different Colon varieties *Rogers* says, in the first of two papers published in 1914, that in the morphology of *B. coli* there is "so little variation that no attempt was made to use this character in differentiation;" whereas he states in the second: "There is a wide variation in both the size and the form of the cell, but since these variations frequently occur within the limits of a single culture they are without varietal significance." The microscopic tests have been made only once with the cultures when 24 hours old, and the motility was not determined at all, as it was considered to be too unstable.

Several important contributions to our subject, however, have been made more recently by American authors. *Noguchi* (1910) proved for the first time that it is possible to transform a nonspore-forming lactobaccillus into a spore-forming member of the Mesentericus group, which fact, though quite probable (*Löhnis*, 1910, p. 200), has never before been tested experimentally. *Maher* (1910–1915) furnished some interesting details concerning the complete life cycle of the tubercle bacillus. Unfortunately, there are some entirely unfounded hypotheses interspersed in his work, which obviously have caused the valuable observations contained therein to be passed practically unnoticed.

The very important contributions, which have been made by *Rosenow* and his coworkers (1912–1917), deserve special discussion on the following pages, like those of *Almquist* and of *Hort*.

(*b*) CAUSES OF APPARENT AND OF GENUINE PLEOMORPHISM.

Before proceeding to review the various explanations given by different authors concerning the much disputed pleomorphism of the bacteria, it seems advisable, to arrange for ready reference in Table I a list of papers wherein data about the pleomorphism shown by the different groups of bacteria may be found. As the presence of branching forms has been frequently considered to be of special importance in regard to the morphology and the systematic position of the bacteria concerned, observations made in this direction have been mentioned in a special column.

TABLE I.

Organisms.	Different cell forms observed.	Branching observed.
Meningococcus	Lehmann and Neumann, 1912; Hort et al, 1915–1916	
Gonococcus	Herzog, 1913	
M. melitensis	Durham, 1898; Babes, 1903; Günther, 1906; Saisawa, 1911; Lehmann and Neumann, 1912; Jordan, 1916, Evans, 1918.	
M. candicans	Löhnis and Smith, 1916	Löhnis-Smith, 1916.
M. flavus	Matzuschita, 1900	Matzuschita, 1900.
M. subnormalis	Hopkins, 1898	
M. rubefaciens	Matzuschita, 1900	Matzuschita, 1900.
M. cyaneus	Beijerinck, 1914	
M. viticulosus	Lehmann and Neumann, 1912	
Sarcinae spec	Lehmann and Neumann, 1912; Löhnis and Smith, 1916	
Urosarcina	Beijerinck, 1901; Miquel and Cambier, 1902	
Sarcinastrum	Lagerheim, 1900	
Pneumococcus and Streptoc. pyogenes	Pansini, 1890; Kruse and Pansini, 1892; Arloing and Chantre, 1894; Babes, 1895; Crookshank, 1896; Stolz, 1898; Ohlmacher, 1902; Taddei, 1909; Broadhurst, 1915, Mallory and Medlar, 1916.	Babes, 1896; Seitz, 1896; Crookshank, 1896; Stolz, 1898; Vincent, 1902, Kraskowska and Nitsch, 1918.
Streptoc. lactis	Billroth, 1874; Maddox, 1885; Burri, 1898; Düggeli, 1905; Löhnis, 1907; Wolff, 1908.	
Poliomyelitis	Rosenow et al., 1916–1917; Nuzum, 1916; Mathers, 1917	
Enterococcus	Thiercelin, 1899–1903	
Leuconostoc	Van Tieghem, 1879 *c*; Ludwig, 1896; Hlava, 1902	
Proteus	Hauser, 1885; Jaeger, 1892; Kohlbrugge, 1901; Höflich, 1902; Matzuschita, 1902; Stefansky, 1902.	Matzuschita, 1902; Stefansky, 1902.
Bact. Zopfii	Kurth, 1883; Schedtler, 1887	Schedtler, 1887.
B. acidophilus bifidus etc.	Sternberg, 1898; Moro, 1900; Tissier, 1900; Cahn, 1901; Rodella, 1901–1908; Sandberg 1904; Noguchi, 1910; Blühdorn, 1910; Bertrand, 1913.	Moro, 1900; Tissier, 1900; Cahn 1901; Blühdorn, 1910.
Lactobacilli from milk, cheese, etc.	Henneberg, 1901; Holliger, 1902; Freudenreich and Thöni, 1905; Düggeli, 1905; Löhnis, 1907; Heinemann and Hefferan, 1909; Rubinsky, 1910; Chatterji, 1910; Koegel, 1914.	Freudenreich and Thöni, 1905; Heinemann and Hefferan, 1909; Rubinsky, 1910.
B. acidi propionici b	Freudenreich and Jensen, 1906	
B. funduliformis group	Hallé, 1898; Ghon and Sachs, 1905; Ghon, Mucha and Müller, 1906; Kisskalt, 1906.	Hallé, 1898; Ghon and Sachs, 1905.
B. erysipelatos	Karlinski, 1889; Rosenbach, 1909	Rosenbach, 1909.
B. septicaemiae (Pasteurella)	Rosenfeld, 1901; Nowak, 1908	Rosenfeld, Phisalix, 1902, Nowak.
B. pseudotuberc. rodentium	Galli-Valerio, 1903, 1913; Zlatogoroff, 1904	Galli-Valerio, 1903.
Bact. pestis	Albrecht and Ghon, 1900; Skschivan, 1900; Cacace, 1903; Dieudonné, 1903; Galli-Valerio, 1903; Zlatogoroff, 1904; Rowland, 1912–1914.	Albrecht and Ghon, Skschivan, Cacace, Dieudonné, Galli-Valerio, Kodama, 1908; Rowland, 1914.
B. influenzae	Crookshank, 1896; Grassberger, 1898; Davis, 1907	Grassberger 1898.
B. pneunomiae, ozaenae, etc.	Bordoni-Uffreduzzi, 1888; Simoni, 1900; Jehle, 1902; Lepeschkin, 1904; Löhnis, 1905; Péju and Rajat, 1906; Toenniessen, 1913; Ward, 1917.	Bordoni-Uffreduzzi, 1888; Lepeschkin, 1904; Löhnis, 1905.
B. coli	Haslam, 1898; Adami et al., 1899; M. E. Abbott, 1900; Matzuschita, 1900; Ohlmacher, 1902; Péju and Rajat, 1906; Wilson, 1907; Revis, 1912; Kellerman and Scales, 1916; Prell, 1917.	Walker and Murray, 1904; Wilson, 1907.
B. dysenteriae	Péju and Rajat, 1906; Hata, 1908; Almquist, 1917	Hata, 1908.
B. typhi	Almquist, 1893; 1894, 1916; Walker and Murray, 1904; Péju and Rajat, 1906; Wilson, 1907.	Gamaleia, 1900; Casagrandi, 1901; Almquist; Walker and Murray, 1904; Wilson, 1907.
B. radiobacter and radicicola	Beijerinck, 1888, 1890; Prazmoski, 1890; Hiltner and Störmer, 1903; Löhnis, 1905; Rossi, 1907; Harrison and Barlow, 1907; Georgewitch, 1916.	Beijerinck; Dawson, 1899; Hiltner and Störmer; Löhnis; Harrison and Barlow, Conn, 1909.
B. rubiacearum	Faber, 1912; Georgevitch, 1916	Faber, Georgevitch.
B. tumefaciens	E. F. Smith, 1911	E. F. Smith, 1911.
Acetic acid bacteria	Hansen, 1879, 1894; Zeidler, 1896; Henneberg, 1897, 1898; Janke, 1916.	Henneberg, 1897, 1898.
Photobacteria	Beijerinck, 1889; Barnard, 1899; Molisch, 1903, 1904; Reinelt, 1905.	Beijerinck, 1889; Barnard, 1899.
Bact. solare	E. Wolff, 1898	E. Wolff, 1898.
B. Fraenkelii	Hashimoto, 1899	Hashimoto, 1899.
B. prodigiosum	Wasserzug, 1888; Slater, 1891; Davis, 1901	Slater, 1891.
B. violaceum	Zopf, 1885; Harrison and Barlow, 1905	Harrison and Barlow, 1905.
B. fluorescens and pyocyaneum	Guignard and Charrin, 1887; Schürmayer, 1895; Wassermann, 1903; Wilson, 1907; Löhnis and Smith, 1916.	Gamaleia, 1900; Wilson, 1907; Löhnis and Smith, 1916.
Ps. cerevisiae	Fuhrmann, 1906	
B. ferrugineum	Rullmann, 1897–1900	Rullmann, 1897–1900.
Nitrosomonas	Winogradsky, 1892	
Nitrobacter	Winogradsky, 1891	
B. mycoides	Olsen, 1897; Nadson and Adamovic, 1912	Olsen. 1897.
B. anthracis	E. Klein, 1883, 1885; DeBary, 1884; Braem, 1889; Rodet, 1894; Crookshank, 1896; Matzuschita, 1900; Lignières and Durrieu, 1902; Henri, 1914.	Lignieres and Durrieu, 1902; Henri, 1914.
B. subtilis	Klein 1885; Löhnis and Smith, 1916	Löhnis and Smith, 1916.
Tyrothrix	Duclaux, 1883; Winkler, 1895	
B. cohaerens	Gottheil, 1901	Gottheil, 1901; A. Meyer, 1901.

Table I—Continued.

Organisms.	Different cell forms observed.	Branching observed.
B. mesentericus	Löhnis and Smith, 1916	Löhnis and Smith, 1916.
B. megaterium	DeBary, 1884; Stoklasa, 1898; Lehmann and Neumann, 1912	Gamaleia, 1900.
B. tumescens	Zopf, 1883; A. Koch, 1888; Garbowski, 1907	
B. oxalaticus	Kuntze, 1904	
B. malabarensis	Löhnis and Pillai, 1907	
B. azotobacter	Beijerinck, 1901; H. Fischer, 1905; Löhnis and Westermann, 1908; Krzemieniewski, 1908; Peklo, 1910; Prazmowski, 1912; Löhnis and Hanzawa, 1914; Löhnis and Smith, 1916.	H. Fischer, 1905; Löhnis and Westermann, 1908; Löhnis and Smith, 1916.
Other aerobic spore-forming bacilli.	Pansini, 1890; Russell, 1892; Niessen, 1898; Gottheil, 1901; Miquel and Cambier, 1902; Neide, 1904; Maassen, 1904; Garbowski, 1907; Proca and Danila, 1910; Viehoever, 1913; Löhnis and Smith, 1916.	Niessen, 1898; Maassen, 1904; Löhnis and Smith, 1916.
B. alvei	Harrison, 1900	Harrison, 1900.
B. amylobacter	Prazmowski, 1880; Buchner, 1882; Van Tieghem, 1884; Schattenfroh and Grassberger, 1900; Winogradsky, 1902; Grassberger, 1902, 1905; Grassberger and Schattenfroh, 1907.	
B. Chauvoei	Ehlers, 1884; Fraenkel and Pfeiffer, 1895; Piani and Galli-Valerio, 1895; Ghon and Sachs, 1903; Grassberger, 1903, 1905; Grassberger and Schattenfroh, 1907; Hibler, 1908.	Ghon and Sachs, 1903.
B. oedematis	Grassberger, 1903; Ghon and Mucha, 1905	Grassberger; Ghon and Mucha.
Cellulose bacilli	Prazmowski, 1880; Omelianski, 1902	
B. tetani	Kanthack and Connell, 1897; Hibler, 1908	Kanthack, 1896; Tavel, 1898.
Vibrio cholerae	E. Klein, 1885 *a*; Ferrán, 1885; Ermengem, 1885; Dowdeswell, 1889, 1890; Friedrich, 1892; Metchnikoff, 1894; Gruber, 1894; Fraenkel and Pfeiffer, 1895; Cunningham, 1897; Nakanishi, 1900; Gamaleia, 1903; Kolle and Gotschlich, 1903; Almquist, 1904, 1907; Hammerl, 1906; Baerthlein, 1912; Lehmann and Neumann, 1912; Stamm, 1914; Popoff-Tscherkasky, 1914; Olsson, 1915.	Dowdeswell, 1889; Metchnikoff, 1894; Kohlbrugge, 1901; Shibayama, 1902, Hammerl, 1906; Stamm, 1914.
V. cardii	E. Klein, 1905	
V. proteus Buchner	Finkler and Prior, 1884, 1885; Firtsch, 1888; Fuerst, 1914	
V. proteus Kohlbrugge	Kohlbrugge, 1900	Kohlbrugge, 1901.
V. Metchnikovii	Nakanishi, 1901	
V. Rugula	Bonhoff, 1896	Bonhoff, 1896.
V. phosphorescens	Maassen, 1904	Maassen, 1904.
V. saprophiles	Weibel, 1888	
V. nasalis	Weibel, 1888	
V. lingualis	Weibel, 1888	Bajardi, 1903.
Spirillum undula	Kutscher, 1895; Lehmann and Neumann, 1912	Kutscher, 1895.
Spir. rubrum	Meirowsky, 1914	Reichenbach, 1901; Meirowsky, 1914.
Sp. endoparagogicum		Sorokin, 1887, 1890.
Spir. bataviae		Faber, 1912.
Spir. pyogenes	Doerr, 1905	Doerr, 1905.
Sp. tyrogenum	Meirowsky, 1914	Meirowsky, 1914.
Spirochaeta pallida	Wechselmann and Loewenthal, 1905; Sobernheim, 1907; Krzysztalowicz and Siedlecki, 1908; Meirowsky, 1914.	Meirowsky, 1914.
Sp. gallinarum	Hindle, 1911	Meirowsky, 1914.
Sp. balanitidis		Meirowsky, 1914.
Sp. Obermeieri	Sobernheim, 1907; Karwacki, 1912	
Sp. icterohaemorrhagica	Inada et al., 1916	Inada et al., 1916.
Spiroch. suis	Ruether, 1910	
Abortus bacillus	Preisz, 1903	Preisz, 1903.
Necrosis bacillus	Schmorl, 1891; W. Ernst, 1902	Schmorl, 1891; W. Ernst, 1902.
Streptob. pellagrae	Tizzoni and Angelis, 1913–1915	Tizzoni and Angelis.
Glanders bacillus	Th. Smith, 1890; Semmer, 1895; Marx, 1899; Galli-Valerio, 1899, 1900; Conradi, 1900.	Semmer, Marx, Galli-Valerio, Conradi.
B. diptheriae	Zarniko, 1889; Escherich, 1894; Zupnik, 1897; Madsen, 1897; Meyerhof, 1898; Kurth, 1898; Wesbrook et al., 1900; Ohlmacher, 1902; Beck, 1903; Spirig, 1903; Goodman, 1908; Smirnow, 1908; Dale, 1910; Balfour, 1911*d*; Morse, 1912; Baerthlein, 1913; Bernhardt and Paneth, 1913; Park and Williams, 1914; Heinemann, 1917; Bergstrand, 1918.	E. Klein, 1890, 1894; Fraenkel, 1895; Bernheim and Folger, 1896; Kanthack, 1895; Meyerhof, 1898; Kurth, 1898; Hill, 1899, 1902; Cache, 1901; Concetti, 1901; Beck, 1903; Cappellani, 1910; Park, 1914; Bergstrand, 1918.
Diphtheroid bacilli	Escherich, 1894; Seitz, 1896; E. Klein, 1900; Nakanishi, 1900; Morse, 1912; Bernhardt and Paneth, 1913; Trautmann and Gaethgens, 1913; Negri and Mieremet, 1913; Lanford, 1914; E. Negri, 1916; Walker and Adkinson, 1917; Mellon, 1917.	Babes, 1895; Kanthack, 1896; Nakanishi, 1900.
B. leprae	Babes, 1883; Lutz, 1886; Bordoni-Uffreduzzi, 1888; E. Levy, 1897; Czaplewski, 1898; Teich, 1899; Barannikow, 1900, 1902; Kedrowski, 1901, 10; Babes, 1907; T. S. Williams, 1911; Galli-Valerio, 1912; Reenstjerna, 1912; Wolbach and Honeij, 1914.	Czaplewski, 1898; Kedrowski, 1901, 1910; T. S. Williams, 1911; Johnston, 1917.
B. tuberculosis	Klebs, 1883; Babes, 1883; Zopf, 1883; Malassez and Vignal, 1884; Lutz, 1886; Metchnikoff, 1888; Cornil and Babes, 1890; F. Fischel, 1893; Coppen-Jones, 1893, 1895; Bruns, 1895; Semmer, 1895; Olsen, 1897; Babes and Levaditi, 1897; Marpmann, 1897; Ferrán, 1897; Schumowski, 1898, 1899; Schuermayer, 1898; Schulze, 1899; Lubarsch, 1899; Arrigo, 1900; Courmont and Descos, 1902; Herzog, 1903; Wolbach and Ernst, 1903; Hawthorn, 1903; Schroen, 1904; Piery and Mandoul, 1904; Arloing, 1908; Betegh, 1908; Much, 1908, 1909; Maher, 1910–1915; Kryloff, 1911; Galli-Valerio, 1912; Wherry, 1913.	Metchnikoff, 1888; E. Klein, 1890, 1894; Mafucci, 1892; F. Fischel, 1893; Coppen-Jones, 1893, 1895; Semmer, 1895; Kanthack, 1896; Olsen, 1897; Marpmann, 1897; Schuermayer, 1898; Dorset, 1901; Wolbach and Ernst, 1903; Schroen, 1904; Miehe, 1908; Galli-Valerio, 1912.
Pseudo-tuberculosis bacilli	Preisz, 1894; Korn, 1899; Moëller, 1899; Lubarsch, 1899; Bongert, 1901; Abbott and Gildersleeve, 1902; Courmont and Descos, 1902; Schabad, 1904; Sanfelice, 1905.	Korn, 1899; Schabad, 1904; Sanfelice, 1905.
Mycobacterium spec	Söhngen, 1913; Chantemesse et al., 1917	Söhngen, 1913; Chantemesse et al., 1917.
Actinomyces spec	Bollinger, 1877; J. Israël, 1878; O. Israël, 1884; Nocard, 1888; McFadyean, 1889; Bostroem, 1890; Eppinger, 1890; Kedzior, 1896; Rullmann, 1896, 1898; Lachner-Sandoval, 1898; Schuermayer, 1900; Silberschmidt, 1901; Neukirch, 1902; Feistmantel, 1902; MacCallum, 1902; Doepke, 1902; Nakayama, 1906; Hollandt, 1906; Loele, 1908; Claypole, 1913; Th. Cohn, 1913; Krainsky, 1914.	All authors mentioned.
Leptothrix	Miller, 1883; Zopf, 1883, 1885; Dobrzyniecki, 1897; Beust, 1907.	Dobrzyniecki, 1897.
Cladothrix	Cohn, 1875; Zopf, 1881, 1882; Billet, 1890; Büsgen, 1894; Migula, 1900; Ellis, 1912.	Cohn, 1875; Zopf, 1882; Migula, 1900.
Beggiatoa	Zopf, 1881–1883, 1895; Engler, 1882; Billet, 1890	
Crenothrix	Zopf, 1879; Schorler, 1904	
Clonothrix	Schorler, 1904	Schorler, 1904.

There is no doubt, and the facts to be discussed later will amply support the statement, that a wide pleomorphism has been observed within all groups of the bacteria by numerous authors. And if at the present time several authors still firmly defend the morphological constancy and simplicity of the bacteria, and do not hesitate to declare beforehand that "any evidence which may be presented to the contrary is based upon untrustworthy methods of observation," we are reminded of many cases in the history of science where newly discovered facts have been strongly opposed by scientific dogmatism. When, e. g., *Sir Thomas Brown* first attacked the time-honored dogma of the spontaneous generation of mice and other vermin from putrefying material *Alexander Ross* commented on this point: "To question this is to question reason, sense, and experience" (*Frost* and *McCampbell*, p. 9). *Oznam* wrote still in 1820 against the theory of the "contagium animatum," though it was supported by men like *Kircher*, *Vallisneri*, *Réaumur*, *Plenciz*, and *Frémont:* "Ich will keine Zeit verlieren, diese abgeschmackten Hypothesen zu widerlegen" (*Loeffler*, 1887, p. 11). *Pineau's* (1845 *a*) remark that frequently the facts recorded "sont entachés d'un esprit de système qui perce dans les resultats" fits also remarkably well to many a report on microscopic studies done from a monomorphistic point of view.

But a great deal of the opposition which has been raised against the pleomorphistic theory was much more based on misunderstanding than on adverse facts. The old mistake to consider the acknowledgment of the occurrence of different cell forms within one species as equivalent to an acceptance of the theory of spontaneous generation or to an inclination to cancel all differentiation of species, still takes a prominent place in some textbooks despite its absurdity. In many other cases a different use of the word pleomorphism has been responsible for much useless debate. *Migula* (1897, p. 229; 1904, p. 47) and *Schmidt* and *Weis* (1902, p. 86) want to have the term restricted, as had been done by *DeBary* (1884, p. 136) for the fungi, to such cases where the complete life history of a bacterium is composed of several subcycles characterized by different morphology. Occurrence of any of the so-called involution forms should not be taken as indicative of a pleomorphous character, according to these authors. To *Migula* (1904, p. 37), however, involution forms are *all* cell forms differing from the normal appearance of the species or variety concerned, irrespective of their origin ("ohne Rücksicht auf das Zustandekommen dieser Abweichung"). Such reasoning naturally would never allow the discovery of any pleomorphism, how evident it may be. Also, in this case it is "le système qui perce dans les résultats."

Hueppe (1886, p. 38) points out that pleomorphism and variability of the cell form should be kept entirely separate. *Rodet*, on the other hand, in his book entitled "La Variabilité dans les Microbes" (1894, p. 38), speaks of "pléomorphisme" when temporary, of "variation" when constant variations of the form are observed. The occurrence of involution forms is characterized by him (p. 39) as "pléomorphisme monstrueux ou morbide." In *Pringsheim's* book on "Variabilität niederer Organismen" (1910, p. 25) pleomorphism is taken as part of morphological variability in about the same manner as advocated by *Migula*.

Considering such inconsistencies and differences of opinion, it seems best to use—at least at the present time—the term pleomorphism in the common though somewhat loose sense, merely indicating that various cell forms have been observed with one or the other species of bacteria. In face of the unsatisfactory situation of the whole problem it seems useless to ascribe to the term a sharply defined meaning, while in too many cases we have not yet secured the correct interpretation of the facts observed.

When explaining an apparent or a real pleomorphism of a bacterium one or the other or several of the following possibilities will have to be taken under consideration:

(1) Contamination.
(2) Incorrect classification of the pleomorphous organism among the bacteria.
(3) Presence of abnormal ("involution") forms.
(4) Occurrence of variations and of mutations.
(5) The normal development of different forms in the various stages of the complete life cycle of a species.

(1) CONTAMINATION.

To *Gaffky* (1881), as to many other followers of *R. Koch*, every change of a culture in form or virulence was an indisputable proof of "contamination." Of course, in many cases this suspicion was and will be fairly well founded, and the practical aims of the bulk of bacteriological work done will often justify a speedy discarding of such cultures without further test. However, as far as scientific investigations come into view, this widespread practice should not be followed too readily. At least in research laboratories the benevolent institution of the "suspended sentence" should be granted in some cases. Already in 1885 *Gruber* quite correctly questioned the dogmatic standpoint taken by *R. Koch* and his pupils, asking:

> Muss man wirklich sobald man eine Aenderung der gezüchteten Bacterien wahrnimmt . . . die unreine Kultur fortwerfen?

Our own studies upon the life cycles of the bacteria started originally from two apparently contaminated cultures of Azotobacter (*Löhnis* and *Hanzawa*, 1914). And it is hoped that this review of the literature will help to stimulate a somewhat more cautious and more scientific treatment of this special point whenever feasible.

Hort (1916 *a*) says that the neglect of bacterial morphology has "led many a worker to assume that perfectly genuine examples of pleomorphic activity are merely examples of contamination," and "a careful scrutiny of alleged contaminations is absolutely fundamental."

When *Winogradsky* (1888) contested *Zopf's* (1881–1885) standpoint concerning the sulphur bacteria, he, like *Zopf*, drew his conclusions from mixed cultures, wherein he, like *Zopf*, saw all kinds of different and intermediate forms. But he did not hesitate to declare all these to be different species, and the monomorphistic view prevalent at that time did neither ask for proofs, nor did it pay any adequate attention to *Zopf's* answer (1895), which hardly ever has been quoted.

When *Gasperini* (1889) first studied the pleomorphism of the Actinomycetes (*Streptothrix Foersteri*), the preparates made up of coccoid forms, short and long rods, threads and screws, appeared to him like "une culture de bactéries fortement impure," and the interesting *Actinomyces* (Cladothrix) *asteroides* found by *Eppinger* (1890) in a case of pseudotuberculosis (cladothrichica) was at first thrown away as contamination. *Kitt* (1897–1898) discarded as "contamination" the Streptothrix growth which he obtained in virulent cultures of *B. erysipelatos suum*. No word is said about an adequate test, and analogous results secured by *Rosenbach* (1909) make it indeed very probable that also here the facts were vanquished by the theory. *H. U. Williams* (1912) isolated from a case of tuberculous pericarditis a spore-forming bacillus and a "Streptothrix," also spore-forming. Only after years a "separation" could be achieved, and then the bacillus frequently became so similar to the "Streptothrix" that the author further remained in doubt whether both are really different species or only stages of one organism. When I (1905 *a*) first studied the various morphological changes of *B. pneumoniae*, *lactis viscosum*, *radiobacter*, and *radicicola*, it also took some time before I was satisfied that all these alterations were indeed not the result of contamination. The close parallelism of the results obtained with the various cultures helped much to solve the problem.

With the Coryne- and Mycobacteria such puzzling cases are especially frequent. To *Spirig* (1903) we owe a thorough discussion of these questions as relating to the diphtheria organism. A "contamination" with a "Streptothrix," first (1899) considered by him to be a type of growth of the diphtheria bacillus, led to a close study of the subject (1903, p. 443). *Duval* (1914), like *G. A. Hansen* (1903), thinks that the lepra organism must invariably represent itself as a simple, constantly acid-fast bacillus. The now very numerous findings which strongly militate against this assumption had therefore to be discredited. The following quotation is very characteristic (*Duval*, 1914):

> In the cases showing diphtheroids and streptothrical forms and acid-fast rods, the recognition of these as separate and distinct species, or the determination of any one or all of them as contaminators was often extremely difficult. So much so that in these cases the cultures were discarded.

Harris and *Wade* (1915) found diphtheroid organisms to be a rather common occurrence not only in and on the body, but also in air, water, etc. The strains isolated by them were

(apparently) quite constant. Accordingly, *Kedrowski's* very extensively studied leprosy cultures, as well as others of pleomorphous character, are declared to be mixtures of different organisms. *Bayon* (1915, p. 29) remarks very aptly that to discard in leprosy studies all diphtheroids because of their ubiquity—

> would considerably simplify pathology. The microörganisms of syphilis, of tuberculosis, of cholera could also, on similar ground, simply be ruled out of court as far as their etiological significance is concerned.

The most recent studies upon the variations and mutations, shown by the bacteria, have helped to make one point clear, which is very important in this connection. As was probably first emphasized by *Firtsch* (1888), it does not infrequently happen that changes shown by some cells of a pure culture may persist for a more or less considerable length of time. Such cases naturally are most liable to be mistaken for contaminations. One of *Bernhardt's* publications (1915) furnishes interesting details relating to this point.

Usually, however, proper experimenting will soon succeed in bringing about such retrogressive changes which will settle the question. Otherwise, parallel tests will be very helpful. If they are incorporated in bacteriological routine work as they are used, e. g. by the chemist, the decision concerning presence or absence of contamination becomes not too difficult, provided, of course, that reliable methods are judiciously used.

(2) INCORRECT CLASSIFICATION OF PLEOMORPHOUS ORGANISMS AMONG THE BACTERIA.

The second possibility mentioned above, i. e. the assumption of an incorrect classification of an organism as a bacterium, has also been used quite extensively to eliminate pleomorphic organisms, rightly or wrongly.

F. Cohn (1872*b*, p. 139) stipulated that a bacterium can only multiply by fission. As true branching necessarily implies budding, it was declared by him never to occur with bacteria, despite the positive findings of *Dujardin* (1841) and *H. Hoffman* (1869), which were soon after confirmed by *Lister* (1873). The monomorphistic theory, as it developed on the foundation laid by *Cohn*, necessarily enhanced this stipulation. Undoubtedly true branching was often declared to be "false" branching, or if this was not feasible, the occurrence of branched forms was frequently considered to be sufficient reason to declare an organism a fungus, though it otherwise showed all characters of a genuine bacterium. The heavy weight of dogmatism is clearly demonstrated, e. g. in *Eppinger's* paper on his *Cladothrix asteroides*. As we know now, this organism is much inclined to exhibit true branching, and this was quite correctly described by *Eppinger* (1890) in the following manner, based on continuous microscopic observation: "A short thread first bends itself, a small granule becomes visible at this place, this develops into a little wart and further into a lateral sprout." Yet, curiously enough, the author calls this process a pseudo-ramification.

The tubercle bacilli were the first to show clearly true branching so frequently that it could not be simply discarded as "false." *Metchnikoff* (1888 *a*) separated them, therefore, from the bacilli and gave them the new name *Sclerothrix Kochii*. *F. Fischel* (1893) declared the tubercle bacilli to be the parasitic growth of a pleomorphic organism, probably belonging into a genus of higher fungi, an assumption which had been made before by *E. Klein* (1890) in regard to tubercle as well as to diphtheria bacilli. *Coppen-Jones* (1893–1896), who first was of the opinion that a special fungus accompanied the tubercle bacilli, later proposed the new genus name Tuberculomyces, and thought that also other pathogenic bacilli might be merely a type of growth of some higher fungi. *Conradi* (1900) declared the glanders bacillus to be a fungus, and wanted to have all bacteria which would show branching incorporated among the Hyphomycetes. *Levy* and *Klemperer* (1900), *Cornet* and *Meyer* (1903), *Jordan* (1909), *Carpano* (1913), and others took a similar standpoint. *Lehmann* and *Neumann* (1912) emphasize the many points which suggest a true natural relationship of the diphtheria, glanders, tubercle, and leprosy organisms, including their so-called pseudo forms, with the Actinomycetes, and consider the whole group either as a connecting link between bacteria and fungi, or as some lower Hyphomycetes.

The latter question has always been answered in a different manner. *Bollinger* (1877), *Gasperini* (1889), *Domec* (1892), *Lachner-Sandoval* (1898), *E. Levy* (1898), *Levy* and *Klemperer* (1900), *Neukirch* (1902), *A. Fischer* (1903), *Miehe* (1908), and others consider the Actinomycetes to be true fungi. *Kruse* (1896 *d*), on the other hand, says:

> Es kann kaum einem Zweifel unterworfen sein, dass die Ähnlichkeit der Streptotrichen mit den Schimmelpilzen nur eine äusserliche ist, während sie den Bakterien nahe verwandt sind.

Meyerhof (1898), *Haas* (1905), *Peklo* (1910), and *Th. Cohn* (1913) also are not in favor of uniting Actinomycetes and fungi. *Bostroem* (1890) concludes from his extensive study of *Actinomyces hominis*, that this organism—though in the paper always called "Pilz" (fungus)—should be placed among the lower algae, next to *Cohn's* Cladothrix. Data concerning the reproductive organs, which will be discussed in Chapter II, indeed strongly indicate a natural relationship of Actinomyces, Cladothrix, and Crenothrix. *Günther* (1906), like *Fraenkel* (1891), still adheres to the older view, placing Cladothrix, Crenothrix, and Beggiatoa among the lower algae. *Zopf* (1881–1882), *Lachner-Sandoval* (1898), *A. Fischer* (1903), *Ellis* (1912), and others, however, prefer to accept them as higher or trichobacteria. The various facts concerning the formation and development of the reproductive organs (to be discussed in Chap. II) support this view.

When considering these problems it must be kept in mind that those characters which have been accepted for a long time as quite specific for the Actinomycetes and related organisms—viz., budding, branching, and apical growth—are by no means restricted to this particular group, but are quite common in all groups of the bacteria. This relationship is enhanced on the one side by the occurrence of motile stages within the life cycles of Actinomycetes and trichobacteria, on the other hand by a distinct similarity of the reproductive organs, formed by these organisms, as well as by the so-called true bacteria.

The fact that all bacteria show budding unquestionably militates somewhat against the time-honored conception of the "Schizomycetes," but it can not longer be justly disputed. Bacteria multiply in their vegetative state not only by fission but to some extent also by budding.[1]

That budding and fission are by no means so different as is usually emphasized in bacteriological textbooks had been already clearly pointed out by *Charles Darwin* (1868), who said (Vol. II, p. 430) that both are "essentially alike." They pass into each other almost imperceptibly. And he quotes *Huxley*, who wrote: "Fission is little more than a peculiar mode of budding."

The data collected in Table I (p. 17) showed that true branching has been actually observed with representatives of all groups of the bacteria. The smallest number of positive findings had to be recorded, quite naturally, with the cocci; but with these organisms distinct budding—the beginning of all true branching—has been found to be quite common. As early as in 1874 *Billroth* noticed that lactic acid streptococci exhibit occasionally "yeast-like branching" (p. 73). *Hueppe* (1891) thought that the budding forms which he found with cocci, rods, and threads, might indicate some relationship to Torula and Saccharomyces. *Kruse* and *Pansini* (1892), as well as *Adametz* (1895), brought further proof concerning the large yeast-like forms produced by streptococci. *Garnier* (1907) named one species explicitly *B. moniliformis*. The so-called bottle bacillus of *Unna*, though it usually grew in the form of a coccus of 1 μ diameter, and also showed culturally all marks of a genuine bacterium, has been removed by *Dold* (1909–1910) under the name of *Dermophyton Malassez* to a place between Hyphomycetes and Blastomycetes. *Meirowsky*, as well as *Kraus* (1913), are much inclined to see some "yeast" in it, on account of its budding. *E. de Negri* (1916) developed a similar culture of "Blastomycetes" (up to $5\frac{1}{2} \times 14$ μ) from a typical Corynebacterium. *Hort* (1917 *b*) placed the meningococcus among the Hemiascomycetes on account of its gemmation and multiple endosporulation. *Laurent* (1891) suspected the budding and branching nodule bacteria to be some form of a yeast or a Ustilago. The same assumption was made by *Calmette* (1893) in regard to a

[1] *Metchnikoff* (1888 *a*) wrote 30 years ago: "Aus den mitgeteilten Thatsachen kann man u. A. sehen, dass die Vermehrung durch Knospung der Familie der Bacteriaceen keineswegs so principiell abgeht, wie es gewöhnlich angenommen wird."

spirilliform organism found by him in cases of typhus, because it grew temporarily in a yeast-like form. And *Ferrán* (1885) saw in the cholera vibrio a type of growth of his so-called *Peronospora Barcinonae.*

The fact that probably all bacteria, especially all bacilli, show true branching has apparently first been pointed out by *Olsen* (1897), who was also of the opinion that bacteria represent some type of growth of Hyphomycetes. Exactly the opposite standpoint was taken by *E. Wolff* as late as in 1898. Even in the case of branching tubercle, diphtheria, and glanders bacilli he was inclined to see only a casual apposition of normal rods. *Gamaleia* (1900, p. 18) stated that all bacteria are able to produce branched forms; but no details are given. That he was right, however, is sufficiently proved by the facts collected in Table I (p. 17).

Lachner-Sandoval (1898, p. 20) thinks that it is "impossible" to classify an organism among the bacteria if it is able to exhibit true branching:

> Die Unterbringung eines typisch verzweigten Organismus unter die Bakterien ist eine Unmöglichkeit.

If this standpoint would be generally accepted, no bacteria would be left at all, and all discussion upon their pleomorphism would become superfluous. However, I believe that there are important scientific, as well as practical, reasons to leave the bacteria in their present place.

Budding, branching, and apical growth alone are undoubtedly no sufficient reasons to advocate any change in their systematic position. In regard to the last-named fact it may be emphasized that apical growth has been always observed at least with all sporulating bacilli during their germination. A closer study of the growing bacteria, under less artificial conditions than customary, in all probability will reveal more interesting details in this respect.

It is not to be denied that these facts enhance to some extent the relations existing between bacteria and fungi. But the relations existing between bacteria, algae, and protozoa should not be overlooked. All bacteria are able to assume more or less the microscopical appearance of an Actinomyces. It has been pointed out why this organism will better take its place at the end of the bacteria, where their line leads over into the realm of the fungi, than among these organisms themselves. That branching occurs more often in young and vigorous than in old and weakened cultures has been shown by *F. Fischel* (1893), *Lubarsch* (1899), *Schulze* (1899), *Migula* (1900), *Concetti* (1901), *Lepeschkin* (1904), *Heim* (1906), *Cappellani* (1911), and others. The opposite statement made by *Günther* (1906) can not be accepted as correct. This lends support to a hypothesis, proposed by *Claypole* (1913), that the Actinomycetes are "representing the ancestral type that gave rise to both the higher fungi and true bacteria."

It has been mentioned above and will be discussed more completely later that a rather close relationship between streptococci and diphtheroids becomes more and more apparent. While the latter in their Actinomyces-like growth approach the fungi, the former have always been considered to be a distinct indication of the relations between bacteria and algae (Nostocaceae). Azotobacter furnishes a similar case. In its typical form it resembles the Chroococcaceae very much. Its spore-forming growth, however, is like that of other bacilli, easily to be induced to assume themi croscopical appearance of an Actinomyces. Crenothrix, also, exhibits clearly this double relationship.

Motility, as well as the formation of endospores, may be taken, as has been done by *Hueppe* (1891) and others, as an indication of phylogenetic relations existing between bacilli and flagellates, and it is not to be denied that much of what has to be discussed in Chapters II–IV concerning other modes of bacterial reproduction is duplicated by analogous facts in the life history of protozoa. Cytological reasons, too, have been repeatedly mentioned in favor of relations connecting bacteria and protozoa. *H. L. Russell* (1892) obtained distinctly monad-like forms from typical rod forms of marine bacilli. Especially in the case of his *Bac. halophilus* (a small motile, asporogenous bacterium) he studied those transformations in the hanging drop successively. Most of the large forms were motile, and it seemed probable to him that monads occurring in the water, but not growing on artificial substrates, were merely types of growth of this bacillus. Fusiform bacilli and spirochaets have been claimed frequently by protozoologists, though also in this case the bacterial nature is well discernible.

On the other hand several resemblances of Schizosaccharomycetes and large bacilli have been pointed out by *Lepeschkin* (1903).

Taking all these facts under consideration, it seems well justified to retain the bacteria in their entirety in their present position, and not to advocate the removal of one species or the other on account of its being inclined to show true branching or another kind of distinct pleomorphism.

(3) ABNORMAL ("INVOLUTION") FORMS.

The third possibility of making pleomorphous bacteria agree with the monomorphistic theory is to declare all "illegitimate" forms to be involution forms, teratologic, crippled, hypertrophic, or otherwise abnormal growth. Only with due recognition of the more or less practical aims of most of the work done in bacteriology it becomes somewhat conceivable how it was possible that so very many unscientific statements have been made in regard to this point.

Lafar (1887, p. 34), *Gotschlich* (1903, p. 43), *Bergey* (1907), *Jordan* (1909, p. 55), and others have correctly emphasized that unusual forms should be termed involution forms only when their degenerate condition is clearly demonstrated by their growth, propagation, and motility, being nearly or completely at a standstill and their cell content usually showing vacuolization granulation, and reduced stainability. *A. Fischer* (1903, p. 47) states that real involution forms are either dying or dead.

Frequently, however, the term is more or less grossly misused. I mentioned that *Migula* (1904, p. 37), for instance, calls involution forms all forms which he considers to be abnormal irrespective of their origin and of their vitality. *Levy* and *Klemperer* (1900, p. 25), *Maassen* (1904), and others take a similar standpoint. *Maassen* enumerates among the causes leading to "teratologic" growth: High or low temperature, liquid or dry condition of the substrates, their reaction, the stimulative effect of large amounts of carbohydrates, and of various salts. He points out specifically that those of the pathogenic organisms are also to be found in the host, sometimes just "when the bacterial development is at its height."

While *H. L. Russell* (1892, p. 194) correctly stated that the big globular forms which he found in old cultures of *B. granulosus* could not, despite this fact, be termed involution forms because they still were multiplying and forming spores, other authors do not hesitate to see "involution" forms even in quite fresh cultures, in spite of the full vitality of these cells. *Ravenel* (1896, p. 30) registered "involution forms" with his *B. cinctus* in cultures 18–20 hours old. Nothing is said about their appearance and behavior. *A. Fischer* (1897, p. 94) made the absurd demand that morphological and cytological studies of the bacteria should never be made with cultures older than 24 hours, because these "do not feel well" after this time:

> Man sollte über einen Tag alte Kulturen niemals zu Studien über den Bau der Bakterien verwenden, da schon nach dieser Zeit . . . die Bakterien anfangen, sich übel zu befinden.

M. Jones (1905) found that "evidence of degeneration" was "conspicuous" with the organism studied after 24–48 hours. But the author also reports that the colonies were only 1–1.5 mm. in diameter after 48 hours, and 5 mm. after 5 days. *Frost* and *McCampbell* (1910, p. 26) state when discussing the involution forms:

> Too rapid reproduction may cause aberrant shapes among some species.

Plotz, Olitzky, and *Baehr* (1915) say that in the cultures of the anaerobic bacillus, which they isolated from typhus exanthematicus, "degeneration and involution forms appear early, so that after repeated transplants the organism may assume a different appearance." *McFarland* (1916, p. 411) goes even so far to assume in regard to the enlarged and clubbed forms of the diphtheria bacillus:

> These probably represent an involution form of the organism, for (!) they are present in perfectly fresh cultures . . . The involution of the diphtheria bacillus seems to occur in proportion to the rapidity of its growth.

Accordingly, he finds the "involution," i. e. degenerate forms, prevalent on good substrates, whereas bad substrates furnished him only "short spindle and lancet shapes."

That, in fact, branched and clubbed forms of the tubercle and diphtheria bacilli are not involution forms has been pointed out in 1890 by *E. Klein*, who apparently was the first to

emphasize the now well-confirmed fact that they are to be found in young cultures as well as in the body. Similar statements have been made more recently in regard to *B. tuberculosis* by *Wolbach* and *Ernst* (1903), in regard to *B. mallei* and *B. diphtheriae* by *Hiss* and *Zinsser* (1914, p. 19), though in the latter case an accompanying picture (fig. 6) still bears the legend "degeneration forms" of *B. diphtheriae*.

Bongert (1901), *Gotschlich* (1903, p. 38), *Kolle* and *Hetsch* (1911, p. 24) accept branching and club formation as a normal stage of growth, whereas *Schmidt* and *Weis* (1902, p. 82), *A. Fischer* (1903, p. 49), *Abbott* and *Gildersleeve* (1903) take the opposite standpoint. The last-named authors do this especially because such forms were not seen regularly on "standard" media. *Migula* (1900, Vol. II, pp. 495, 499) thinks that a priori all branched forms of *B. tuberculosis* and of *B. diphtheriae* are to be considered "involution" forms and "degenerate"[1]). Accordingly, he (*Migula*, 1904, p. 38) declares the swollen and branched forms of *B. radicicola* to be "undoubtedly" involution forms. To *Stefan* (1906) it was even quite certain that they are pathologic. Also *E. F. Smith* (Vol. II, 1911, p. 114) believes that they are degeneration forms, because "such forms are either dead, or, if capable of further growth, return to the original form when placed on suitable media."

More than 30 years ago, however, *Prazmowski* (1888 *b*, 1890) found in the course of his thorough studies upon this organism that the so-called "bacteroids" appear when the development is at its height, and that they reproduce small rods. The latter fact had first been directly observed, 20 years earlier, by *Woronin* (1866), and it was afterwards confirmed by *Frank* (1890), later by *Hiltner* and *Störmer* (1903) and others. *Süchting* (1904) also noticed that "bacteroids" are abundant in the cultures when these are fully developed, whereas in cultures older than 8–14 days numerous small motile rods are present, originating from the branched forms. My own investigations (1905 *a*), as well as those of *Gage* (1910) and *Zipfel* (1911), confirmed and extended these findings. That according to *Morck* (1891), *Harrison* and *Barlow* (1907) the branched forms are prominently located in the growing, active part of the nodules, while in the youngest as well as in the oldest nodules only cocci and rods are present, agrees very well with the results obtained in cultures kept under suitable conditions. *Miehe* (1913), on the other hand, because he could not see further development of branched forms under the microscope, does not hesitate to call them "cripples" and all positive results recorded in the literature "fiction." But the normal rods of the organism used in these experiments (*B. foliicola*) also refused to grow under *Miehe's* microscope, and that his statement concerning the positive findings secured by other investigators is entirely unwarranted, goes without saying.

When *Hauser* (1885) first studied his pleomorphic Proteus, large globular, pear and club shaped forms (3–7μ) were described by him as "involution forms." But he pointed out himself that these very motile forms were already present, and sometimes even prevailed in the colonies when only a few days old, while they were replaced in old liquefied gelatine cultures by the small rods and cocci, characteristic of this group. By direct reinoculation the "involution" forms could be stabilized, so that they reproduced themselves, e. g., in 30 successive transfers, made during seven months.

The well-known "involution" forms of the plague bacillus, which are still virulent, appear in artificial culture within a few days, while again in really old cultures the small "normal" forms alone are present, as has been shown especially by *Albrecht* and *Ghon* (1900). In accordance with this fact, the same forms have been found by *Sata* (1900), *Dieudonné* (1903), and others in the body, showing full vitality and virulence. *Galli-Valerio* (1903) states explicitly that the various forms of *B. pestis* (globules, clubs, threads, branched cells, etc.) are not involution but evolution forms, because they appear first and the short rods later.

The meningococcus produces its "degenerate" giant forms in large numbers in only two days old cultures (*Kutscher* 1907). *Micrococcus melitensis* grows, according to *Eyre* (1907), in bacillary form only in old cultures or when the reaction of the substrate is not right, while

[1] In his own words (l. c., p. 499): "Dass diese Verzweigungen ebenso wie bei zahlreichen anderen Bakterien nichts weiter als Involutionsformen sind, braucht wohl nicht erst besonders hervorgehoben zu werden."

Saisawa (1911) found the rods in young, the cocci in old cultures. *Durham* (1898) has demonstrated that merely a change in the temperature suffices to turn the cocci into bacilli or vice versa; both are equally vital. *Jordan* (1916, p. 416), accepting the rod form as the normal type, calls the organism *Bac. melitensis*. *Kruse* and *Pansini* (1892) were not inclined to think that the rod-like cells produced by pneumo- and streptococci are involution forms, for they were found to be the result of an especially luxuriant development of the cultures. The large yeast-like cells of *Streptococcus lanceolatus* were found by *Axelrad* (1903) in young colonies on the plate.

That the large swollen forms produced by acetic-acid bacteria are not properly termed "involution" forms had been pointed out by *E. Chr. Hansen* as early as in 1879, and it was recently confirmed in the course of detailed studies by *Janke* (1916). *Bordoni-Uffreduzzi* (1888 *b*) said the same concerning the large globular, spindle-shaped and triangular forms occurring in cultures of his *Proteus hominis*. He sees in them an expression of luxuriant growth. Old and weakened cultures showed only the small "normal" rod-like cells. With the ozaena bacillus—another member of the *B. pneumoniae group*—*Simoni* (1900) got analogous results. And these were further confirmed by my own experiments with various nitrogen-fixing strains of the *B. pneumoniae* group (1905 *a*), which shed some interesting light on the relations existing between *B. radicicola, radiobacter*, and *pneumoniae*.

B. Chauvoei is another example of conspicuous pleomorphism. Its characteristic forms occur everywhere, in the cultures as well as in the tissue. But they, too, have been declared by *Fraenkel* and *Pfeiffer* (1895, legend to fig. 60, Pl. XXX) to be degenerate, crippled involution forms, merely because they are entirely unlike the typical cells which "obey the rule" of the monomorphistic dogma.[1]

In their interesting studies upon the morphology of the tetanus bacillus *Kanthack* and *Connell* (1897) correctly emphasize that the branching, club formation and mycelial growth shown by this organism can not be set aside as "involution forms", because they appear in the cultures when 18–24 hours old, and they disappear with increasing age.

The multitude of monstrous forms found by *B. Fischer* (1894, p. 36) to be characteristic for his *Halibacterium polymorphum* becomes visible in cultures not older than 2–3 days, when grown on most suitable substrates.

Baumgarten (1890) called the attention of cholera investigators to the important rôle which the so-called involution and degeneration forms of *V. cholerae* may play in cultures, as well as in the body. *Hammerl* (1906) and *Popoff-Tscherkasky* (1914) have furnished convincing proof that in this case, also, those terms have been greatly misused. All these globular, triangular, spindle-shaped and ramified forms were found to be very motile, abundant, and sometimes even exclusively present in young cultures; they could be propagated as such for weeks and months, and produced again "typical" commas and spirilla. Of special importance, however, is the fact demonstrated by *Bittrolff* (1912) that great variation may be shown in this respect by different strains, especially in the animal test.

Severin (1897, p. 513) wrote in regard to the characteristic triangular branched cells of his *Vibrio denitrificans:*

> Es kann kaum bezweifelt werden, dass wir es hier nicht mit Involutionsformen zu tun haben, erstens finden sie sich nicht in alten Kulturen, sondern im Gegenteil nur in frischen, und . . . derartige Formen färben sich sehr gut und weit gleichmässiger als die Mehrzahl der sich nicht verzweigenden Formen und besonders der Spirillen.

Reichenbach (1901) took the same standpoint concerning *Spirillum rubrum*, and *Bajardi* (1903) obtained branching so frequently in young cultures of *Vibrio lingualis Weibel.* that he thought this organism should be transferred to the Actinomycetes as "*Streptothrix lingualis.*"

Spirochaeta pallida is, according to *Sobernheim* (1907), equally inclined to exhibit "atypical" and "involution" forms within the tissue. And the same holds true in regard to different species which are pathogenic to plants, as has been recorded by *Macchiatti* (1898) and *E. F.*

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[1] "Sehr auffallend ist die ausgesprochene Neigung des Rauschbrandbacillus zur Bildung von Involutionsformen. ma ihm auch begegnen mag, im Gewebssaft der Tiere, in Bouillon, Gelatine oder Agar, fast stets trifft man zahlreiche, wunderlich verzerrt Misswüchse, degenerierte Zellen an, deren verkrüppelte Gestalt kaum noch eine Spur von Ähnlichkeit mit den typischen, vorschriftsmässigen Gliedern besitzt."

Smith (1911, Vol. II, pp. 73, 256, 288). The former author says concerning his *Bacillus Baccarinii* (the causative agent of the "mal nero" of grapevine):

> Die Grösse wie auch die Gestalt dieses Bacillus variieren sehr . . . hier haben wir also einen schönen Fall von Polymorphismus; . . . die verschiedenen Gestalten folgen auf einander, wenn die Mikrobien über günstige Entwicklungsverhältnisse verfügen.

More details to be found on the following pages will amply support the conclusion, which can be drawn from the cases discussed, viz., wherever the so-called involution forms have been made the object of more discriminate studies, nearly invariably it has turned out that it was a mistake to presume their being degenerate, merely on account of their "atypical" appearance. Actually, in many cases they have shown themselves to be constantly occurring stages in the life history of the bacteria. The "typical"—not the so-called involution—forms have been often found to prevail in old cultures, whereas the "atypical" forms were predominant when the development was at its height. *Wasserzug* remarked in 1888 (*b*) that involution forms were sometimes more normally visible than the so-called normal forms. And still earlier *Finkler* and *Prior* (1885) emphasized correctly that it is usually by no means easy to decide definitely whether morphological changes of the bacteria—the so-called involution forms—are to be considered pathologic or normal occurrences within their life history.[1]

The distinctly unscientific trend of opinion, which has been promulgated in this respect by some of *R. Koch's* overenthusiastic pupils, is clearly substantiated by the following quotation, taken from *C. Fraenkel's* "Grundriss der Bakterienkunde" (1891, p. 10). The involution forms, says he—

> gehören nicht in den Entwicklungsgang der betreffenden Bakterienart, sie sind kein notwendiges, unentbehrliches Stück des Weges, welches das einzelne Individuum von Anfang bis zu Ende durchmisst, und verlieren damit den Anspruch auf Legitimität, sind uns nichts weiter als ein Anzeichen dafür, dass unter dem Einflusse ungünstiger Verhältnisse eine Degeneration des Bakterienprotoplasmas stattgefunden hat.

Yet this standpoint has been fully shared by authors like *Macé* (1897, p. 323). *A. Fischer* (1903, p. 49), *Maassen* (1904), *Günther* (1906, p. 22), and others.

The real value of *Fraenkel's* reasoning becomes quite evident when we consider the following two points: In all cases, where purely vegetative propagation is successful, as with all lower, as well as with many higher, plants, all reproductive organs, flowers and fruits, are entirely "unnecessary," can not be accepted as "legitimate" and must be considered as indicating degeneration, because the vegetative growth comes to a standstill at this time. Further *Fraenkel* admits that *B. anthracis* (like many other bacilli) also produces coccoid forms. But he is absolutely certain that these do not form a part of the life cycle of the bacillus, "because" they either do not grow at all, or if they do, they produce again the "regular, typical" rods, i. e. they behave like spores.[2]) The endospores had been studied by *R. Koch*, while other reproductive organs remained unknown to him. Therefore, to *Fraenkel* and to other faithful adherents the former are of greatest importance and the latter entirely "illegitimate."

A comparison of the so-called involution forms with the endospores is of special interest. *Duclaux* observed several decades ago (1883, p. 654) that his *Tyrothrix virgula* and *scaber* produced characteristic swollen forms, resembling spermatozoids, but that only later, within these swellings, the endospores appeared. Our *Bac. malabarensis* (*Löhnis* and *Pillai*, 1907) behaved in exactly the same manner. *Braem* (1889) made some interesting experiments which clearly show that inoculation into water is as useful to stimulate the appearance of the so-called involution forms as it is to induce spore formation. *A. Meyer* (1901 *a*) points out that also branching occurs at an earlier stage of growth than spore formation; and *Heymann* (1903) obtained

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[1] "Wir halten es für ausserordentlich schwierig, sichere Beweise dafür liefern zu können, wo die Grenze liegt zwischen den mannigfachen Variationen der Form, welche als pathologische Zustände der Vibrionen aufzufassen sind, einerseits, und andrerseits solchen Bildungen, welche als physiologische Entwicklungszustände angesprochen werden müssen."

[2] In *Fränkel's* own words (l. c., p. 9): "Gehören nun derartige 'Kokken' in den Entwicklungskreis der Milzbrandbacillen? Gans gewiss nicht. Denn . . . dieselben sind entweder überhaupt nicht mehr fortpflanzungsfähig . . . oder aber sie lassen sogleich wieder die . . . typische Wuchsform, das Langstäbchen von regelmässiger Gestalt aus sich hervorgehen. Es sind diese Gebilde eben nur der Ausdruck für eine stattgefundene Entartung der betreffenden Bakterien, es sind Degenerations- oder . . . Involutionsformen, Misswüchse, die für die Beurteilung des normalen Wachstums gar nicht in Betracht kommen können."

analogous results concerning the "involution" forms of diphtheria bacilli and the (later) appearance of the granules in them giving *Neisser's* staining reaction.

Endospore formation and Neisser reaction have been always accepted by the followers of *R. Koch* as of very great systematic and diagnostic importance. Therefore, the adverse valuation of the "involution" forms, as taught by them, is by no means in accordance with the facts. It would be even more correct to call the endospores involution forms, because they are to be found in old cultures, when motility and vegetative propagation is at a standstill. It is true, some of them, though not all, will produce new rods when transferred to a new substrate. But many of the so-called involution forms act in the same manner, and just this was the reason why several authors discarded them as being of no interest or importance.

Some authors, like *Kruse* (1896 *a*, pp. 61–64), *W. Winkler* (1899), *Gamaleia* (1900), *Fuhrmann* (1906), *Taddei* (1909), *Löhnis* (1913, p. 24) and *Ambrož* (1915), have advocated a closer study of and a more scientific attitude against the so-called involution forms. That their appearance is dependent on external (chemical and physical), as well as on internal (biological) influences, is clearly indicated by the interesting results secured by *Gamaleia* (1900), *Matzuschita* (1900), *Rosenfeld* (1901), *Maassen* (1904), *Péju* and *Rajat* (1906), *Hata* (1908), and *Taddei* (1909), on substrates containing various salts, relatively large amounts of carbohydrates, or possessing an unusual reaction. *Kruse* (1910, p. 8) points out that a special stimulation of growth is frequently responsible for their appearance, whereas *A. Meyer* (1901 *a*) emphasizes that undoubtedly "inner reasons" are the more important ones, because those forms often develop more or less irrespective of substrate, temperature, etc. Accordingly, some species are very much inclined to produce such special growth, while others under analogous conditions show little or no alteration at all (*Migula*, 1897, Vol. I, p. 52). *Fuhrmann* (1908) found, in accordance with *Matzuschita* (1900) that moderate salt concentration merely accelerates the normal growth, while high concentrations, of course, act detrimentally or may eventually cause the death of the cells.

If the vitality of so-called involution forms is not tested very carefully, it may easily happen that incorrect results are recorded. The uniformity of the methods usually employed is liable to cause misleading observations. The difficulties, which have often arisen when new species had to be isolated, should be kept in mind. That a marked periodicity in the progress of cell growth may often become noticeable, when tested on the ordinary substrates, has been demonstrated with pyogenic staphylococci and with dysentery bacilli by *Reimer* (1909) and with diphtheria bacilli by *Springer* (1913). The initial increase only lasts a few days, then (apparently) a reduction takes place, followed again by another maximum, and eventually by more of such waves. The following examples from the last-named author's paper (in round figures and abridged) may elucidate this point:

Germs per cc.	Experiment No. 4.	Experiment No. 5.
At the beginning	3,800	4,176
After 4 days	33,000,000	14,000,000
After 8 days	1,000,000	4,600,000
After 22 days	23,000,000	46,000,000
After 42 days	19,000,000	366,000,000
After 62 days	63,000,000	20,000,000

It would be well worth while to combine such experiments with a close study of the appearance and disappearance of the "involution" forms. It can hardly be questioned, that such investigations would greatly help to modify the prevalent theories concerning the meaning and importance of the different types of bacterial growth.

Looking back upon all those conflicting and often very incongruous statements, which have been made by the bacteriological writers during four decades, one might feel much inclined to agree with *Fokker*, who said as early as 1888 (p. 125) that the term "involution form" is only "a name without any significance." It would be best to drop the term entirely. As this, however, in all probability will not be done, it might be advocated to use the word at least

exclusively in its correct sense. Webster's New International Dictionary (1910) contains the following explanations:

> Involution = retrograde development or retrograde evolution; degeneration.
> Degeneration = a progressive deterioration, as a return to a simpler and less highly organized condition in the evolution.

Accordingly, it would be quite correct to call involution forms the small "normal" forms, which in really old cultures often replace the larger, more highly organized cell types, which have so far been termed involution forms, evidently without sufficient reason. But such practice would only lead to still more confusion. All that can be expected in the future seems to be a somewhat more cautious use of this greatly overworked expression. Specialized studies of the subject would prove very helpful in this respect.

(4) VARIATIONS AND MUTATIONS.

The fourth explanation, which has to be taken under consideration in regard to apparent or true pleomorphism among the bacteria, is the occurrence of temporary, as well as of more or less permanent, changes in the type of growth, called adaptation, modification, variation and mutation. Again much differences of opinion are to be found in the literature concerning the correct use of these expressions. This point has been discussed in the publications of *Pringsheim* (1910), *Nyberg* (1912), *Dobell* (1913), *Toenniessen* (1913), *Jollos* (1914), *Jordan* (1915), and of *Prell* (1917).

For our purposes it will suffice to use preferably the general term "variability," as in practically all cases observed so far, quite naturally cause as well as stability (or instability) of the occurring changes have remained more or less in doubt. In some cases the influence of external conditions and the instability of the change induced by them are evident, in other cases the opposite holds true. How a change of substrate may influence the form of the bacteria has been clearly demonstrated, e. g., by *Wasserzug* as early as 1888. By studies upon the variability of the streptococci, *Lemoine* (1896) was led to the conclusion that not only the influence of the substrate had to be considered, but also the "modifications subies au sein même de l'organisme." *Neumann's* (1897) investigations upon the variability of pigmentation of the micrococci still more indicated a predominance of internal against external causes. *Luckhardt* (1901), *Rettger* and *Sherrick* (1911), *Jordan* (1915), and others have furnished more examples in this direction. That, on the other hand, external conditions occasionally may assume very great importance has been exemplified, e. g., by *Bordet* and *Sleeswyk* (1910) concerning the change of agglutinability in various species, by *Geisse* (1914) in regard to the pathogenicity of saprophytic staphylococci, by *Heinemann* (1915) in regard to pathogenicity and morphology of *Streptococcus lactis*, and by *Bernhardt* (1915) with *B. typhi, dipthheriae*, and others.

With some of the variants obtained in these experiments considerable stability has been recorded. *Hill* (1899) isolated a strain of *B. diphtheriae* which showed branching very persistently. *Lepeschkin* (1904) also succeded in splitting off an equally inclined strain of his *B. Berestnewi*, making use of single-cell cultures. *Barber* (1907), too, obtained from single cells strains possessing morphological peculiarities which were (apparently) constant. Whether the constancy of a new character is in fact real or apparent must necessarily remain in doubt in many cases. For instance, a white Micrococcus strain isolated by *Neumann* grew white for six years and returned then to the original yellow type. One of *Luckhardt's* white Prodigiosus cultures became suddenly red after several months' experimenting, only to return to white afterwards. One of my own stock cultures, a brown variety of *B. fluorescens*, became entirely white after it had been kept for about two years in the collection, always being transferred in approximately three months intervals to beef agar made up in the same manner. The next inoculation produced the brilliant green of a typical Fluorescens, but the next one was brown again, and so it remained through several years. As most observations naturally must be of much shorter duration, the question concerning the stability of a new form will always remain more or less in doubt. It is well known that frequent transfers to the same substrate repeated after

a few days tend to keep a strain constant, whereas older cultures are much more liable to furnish either new variants or to exhibit atavistic tendencies. *Fürst* (1914), e. g., who studied anew and in single-cell cultures the remarkable variability of the Finkler-Prior vibrio, first investigated in mass cultures by *Firtsch* (1888), obtained constant variants when these were transplanted after 5–6 days, whereas by 2½–4 months' intervals the number of atavistic changes was increased, and 4-months-old cultures produced again a growth exhibiting the normal original characters. *Burckhardt* (1914) was able to restore motility in some immotile stock cultures of *B. coli* not by frequent transfers, but by starting from very old material. Immotile strains, on the other hand, could be easily obtained by keeping them under less suitable conditions. These facts are in good agreement with some observations mentioned above concerning the so-called involution forms; we will have to refer to them when discussing the various changes occurring in the different phases of the life cycles of the bacteria.

While the doctrine of constancy, as promoted by *R. Koch* and his pupils, was rather short-lived as far as the *function* of the bacteria comes into view, it has found, on the other hand, up to the present time considerable support in regard to the *form* exhibited by this special group of organisms. As Life, however, is characterized, according to *Spencer*, by the "continuous adjustment of internal relations to external relations," it is, indeed, self-evident that variations *must* occur under changed conditions (*Spencer*, 1898, p. 334). That *all*, morphological as well as physiological, characters of the bacteria may vary has been explicitly stated, probably for the first time, by *Nägeli* (1882, p. 135). The following of his sentences (p. 138) is remarkably accurate when we consider that it was written more than 35 years ago:

> Die Species wird nicht durch absolute Merkmale kenntlich sein, sondern dadurch, dass sie unter bestimmten äusseren Umständen bestimmte Modificationen des morphologischen und physiologischen Verhaltens, unter anderen Umständen andere Modificationen zeigt.

Ziegler (1885, p. 203) also admitted that variability occurs "within definite limits," though it had been more correct to say "indefinite" limits, as he expresses himself as follows:

> As to the extent of the cycle of variations, through which any one of the known bacteria may pass, we know indeed but little.

Among the German and Austrian bacteriologists it was especially *Escherich* (1894), *Hueppe* (1896), *Kruse* (1896, 1910), and *Lehmann* and *Neumann* (1912), who have insisted upon an adequate study of these problems and have done much in reducing the chaos in systematic bacteriology caused by the widespread habit to incorporate into the literature many badly studied instable varieties as constant species. Even *Migula*, who at first was one of the most ardent supporters of the latter practice, had to admit later (1904, p. 35) that several organisms, e. g., the cholera vibrio, are characterized by a very great variability.[1]

Among the French authors *Macé* (1897) takes a distinctly contradictory standpoint, similar to his position in regard to the pleomorphic character of the bacteria. On the one side he says (p. 323):

> On peut affirmer à l'heure présente, avec la probabilité la plus grande, qu'il existe chez les bactéries des espèces vraies, à charactères fixes, se produisant et se perpétuant sans varier.

But only a few pages further on we are informed (p. 329):

> D'une autre côté, il n'est guère possible d'admettre une fixité absolue des charactères que l'on considère comme specifiques. De nombreux exemples preuvent, au contraire, qu'à côté des charactères physiologiques que nous savons variables, les caractères morphologiques eux-mêmes ne nous montrent pas une fixité absolue.

Otherwise, all French bacteriologists are accepting unanimously the variability of the bacteria as a necessary correlative to their pleomorphism, as has already been shown by some of the quotations given above. The following paragraph taken from *Duclaux's* "Traité de Microbiologie" (1898, p. 605) may serve as another characteristic example:

> A ces variations de fonctions viennent se supposer des variations de formes au sujet desquelles les savants avaient fort discuté, les uns soutenant qu'elles étaient assez constantes pour entrer dans la diagnose de l'espèces, les autres

[1] "So zeigt besonders der Organismus der asiatischen Cholera eine ausserordentlich grosse Zahl von Varietäten, die von stark gekrümmten bis fast geraden, von sehr kurzen bis sehr lang gestreckten Zellen fast alle Zwischenformen zeigen und sich dabei in Kulturen auffallend konstant gezeigt haben . . . Diese Varietäten behalten auch auf verschiedenen Nährböden ihre Formen bei, sind also keine 'Ernährungsmodifikationen,' und sie würden, bei unserer gegenwärtig sehr unsicheren Kenntnis von der Umgrenzung naturhistorischer Arten bei den Bakterien, sicher als verschiedene Arten betrachtet werden, wenn sie nicht eben als Erreger derselben Krankheit gefunden wären."

qu'elles étaient indéfinies. On voyait bien maintenant que cette question n'en était pas une, ou plutôt qu'elle disparaissait dernière la question plus grosse et plus profonde des variations de la fonction protoplasmique . . . Bref, a l'idée de spécificité, encore dominante il y a dix ans . . . s'en est substituée une autre, . . . celle de la plasticité de la fonction protoplasmique.

More recently, *LeBlaye* and *Guggenheim* (1914, p. 12) have strongly emphasized the very great variability exhibited by most of the species, which are forming groups of more or less atypical "races."

Among the British authors, it was especially *Adami* who has repeatedly (1892–1916) called the attention of his fellow-bacteriologists to this important problem. In his second paper on this subject (1894) he pointed out that experimentally changes can be produced which would be considered a priori as characteristics of a totally different species, and that on account of the wide variability to be observed under different conditions "the first step must be in the direction of the establishment of a system of broad groups."

In the American literature some discussions upon the variability of the form of the bacteria are to be found in the works published by *Chester* (1901), *Park* and *Williams* (1914), and others. However, as has been illustrated by the quotations given above, the doctrine of simplicity and constancy of the form has been supported by many of the American bacteriologists until quite recently. Moreover, there is even a tendency now to establish not only species, but genera on some biological characters, though the still greater variability of these marks, clearly indicated in the early publications of the French authors (*Guignard* and *Charrin*, *Wasserzug* and others), has been so often confirmed since then that it is now well beyond question. *C.-E. Winslow* and *A. Rogers- Winslow* (*1908*), e. g., have advocated dividing the micrococci into different genera mainly on the basis of their pathogenicity and pigment-production. The systematic relationship of the streptococci, too, should be established, according to the first-named author (*Winslow*, 1912), on the outcome of biometric studies of their fermentative powers, a method which had been advocated, though only for practical purposes, by *Andrewes* (1906) and other British authors. That these very variable properties can not be used for classification has been demonstrated anew by *Broadhurst* (1915) in regard to the streptococci, and by *Burton* and *Rettger* (1917) for the Colon-Aerogenes group. *Kligler* (1913), on the other hand, fully confirms the correctness of *Winslow's* standpoint and claims that there is "a remarkable general correlation between pigment production and other properties." However, white cocci sent to the collection used for these studies were found by *Kligler* to be orange. An organism, originally exhibiting all characters of *Micr. agilis*, was declared by him to be either *M. citreus* or *roseus*, indicating beyond doubt that also in this case the generally observed instability of the physiological properties has exerted its influence.

Numerous papers have been published during the last 10 years, mostly in Europe, wherein the morphological as well as the physiological variability of some groups of bacteria have been more or less thoroughly discussed, usually under the aspect of mutations. This point was first emphasized in the publications of *M. Neisser* (1906), *Massini* (1907), *Penfold* (1911–1912), and *R. Müller* (1912) concerning lactose fermenting "mutants" of *B. coli*. The preliminary communication made by the first-named author was immediately followed by still more interesting remarks by *Schottelius* (1906) and *Gotschlich* (1906) concerning *B. pestis*, and by *Gruber* (1906) in regard to Finkler-Prior's vibrio. The so-called mutation of *B. pestis* has been further studied by *Markl* (1914). *Toenniessen* (1913–1914) added important data upon the variability of *B. pneumoniae*. *Nyberg* (1912) succeeded in producing artificially with all of 140 strains of different lophothrichic bacteria (Fluorescens, Cyanogenes, etc.) those different types of colonies which have been observed in many other investigations on "mutations." *Baerthlein* (1911–1918) obtained them with cholera, typhoid, paratyphoid, dysentery, coli, and diphtheria bacilli, as well as with micrococci, *Bac. proteus* and *pyocyaneus*, and saw them always accompanied by considerable changes of the cell form. *Köhlisch* (1916–1918) and *Gildemeister* (1917) confirmed and extended *Baerthlein's* findings with regard to tne Coli-Typhosus group. The great variability occurring in the diphtheria group has been elucidated to some extent by the investigations of *Ohlmacher* (1902), *Goodman* (1908), *Bernhardt* and *Paneth* (1913), and others. *Stamm*

(1914), *Olsson* (1915), and *Feldmann* (1917) made the cholera vibrio the object of their studies. *P. Eisenberg* (1914–1918) worked with representatives of various groups of bacteria (*Bact. prodigiosum, violaceum, fluorescens, pneumoniae, typhi, coli, dysenteriae,* and *Sarcina tetragena*). However, it would be entirely without foundation to assert that the two foremost marks of true mutation, viz., the sudden appearance and the constancy of the alteration observed, had been sufficiently demonstrated in any or all of these cases. That there *may* have been some true mutation is not to be denied. But the examples given above indicate clearly, how difficult, nay even impossible, it will be to find out in the ordinary course of examination which only lasts some weeks or months, whether the change in fact is constant or not. And whether the new form or function has appeared gradually or indeed suddenly is a problem still more difficult to solve. Accordingly, several authors, like *J. Klein* (1912), *Bernhardt* (1912), *Berry* and *Banzhaf* (1912), *Saisawa* (1913), *Feldmann* (1917), and *Baerthlein* (1918), have emphasized that the alterations actually did not represent mutations, but only temporary adaptations, fluctuating variations or atavistic reactions. As older cultures generally are more inclined to produce aberrant strains, it has been repeatedly assumed that accumulated metabolic products are the foremost cause of the effect. To some extent this is undoubtedly true. But, as with the involution forms, it must be also kept in mind with regard to morphological and physiological variations shown by cultures of various age, first, that only some of them show variability and these again to a different degree, while others do not, and in the second place, that with increasing age of the culture there may be a complete return to the original, so-called typical, character.

Bernhardt (1915), *Olsson* (1915), and others have quite correctly spoken of the "cycle of variation" characteristic for every species or group of bacteria. This cyclic alteration of form and function is, indeed, an important attribute of the normal life cycles of the bacteria. And this fact easily explains, why in all cases more or less variability can be observed from the start, when a sufficiently large number of strains, belonging to one species, is isolated at the same time. Accumulation experiments, as recommended by *Beijerinck* (1898, 1901 *a*), are of very great importance in this respect. *Kruse* (1910, p. 1153) says:

> Es ist von vornherein zu erwarten, dass die natürliche Züchtung in ähnlicher Weise Abarten erzeugen wird, wie die künstliche. Die Erfahrung hat das auch immer wieder bestätigt.

Grassberger (1905) was equally right when he wrote:

> Darüber kann kein Zweifel bestehen, die Natur versteht das Variieren noch viel besser als wir, und auch das Misshandeln, speciell dort, wo es sich um die Wechselwirkung zwischen verschiedenen Organismen dreht.

Some authors have, therefore, strongly advocated to study freshly isolated strains, so as to avoid those "artificial" alterations caused by long continued growth on the substrates used for laboratory work. For instance, *LeBlaye* and *Guggenheim* (1914, p. 10) write:

> Un diagnostic méthodique n'est possible que si l'on opère avec des cultures fraîchement retirées de l'habitat naturel. Ainsi se trouve eliminées les erreurs innombrables qui résulteraient des modifications que subissent les caractères morphologiques et biologiques des espèces sous l'influence du séjour dans les milieux artificiels.

On the other hand, the "standardization" not only of the methods to be applied, but of the bacteria themselves to the extent of eliminating all natural varieties, has been also recommended. *R. Koch's* pupils, the representatives of the extreme monomorphism, naturally took the leadership in this respect. *Fraenkel* (1891, p. 10) said:

> Wenn man dafür sorgt, dass ein solches (i. e. apparently pleomorphic) Bakterium dauernd unter gleichmässig günstigen, unter den besten Ernährungs- und Wachstumsbedingungen steht, so bleiben die abnormen Formen aus, und wir bekommen einen einheitlichen, fest umschriebenen Eindruck von seinem äusseren Verhalten.

However, it is by no means certain, whether the ordinary standardized laboratory methods will afford the most suitable conditions of growth. In fact, another statement in *Fraenkel's* book (p. 132) explicitly admits that undoubtedly many microörganisms do not grow at all on the media commonly used, and—

> Die Eintönigkeit des Verfahrens ist gewiss häufig die Ursache für das Fehlschlagen der Culturversuche.

Kruse (1896, p. 476; 1910, p. 1125) says:

Die Milzbrandbacillen von Maus auf Maus übertragen, das Essigbakterium immer frisch mit alkoholischer Nahrung gespeist, der Prodigiosus von Kartoffel auf Kartoffel übertragen, verändern sich nicht, so lange man auch das Experiment fortsetzt.

But as early as 1879 *E. Chr. Hansen* showed that the acetic acid bacteria in alcoholic fluids, where they grow best, are very much inclined to undergo conspicuous changes in their morphology, while they are "typical" small rods in the weakly growing layers on artificial substrates. The anthrax bacillus, on the other hand, will never show its very characteristic spore formation, when it is transferred in quick succession from mouse to mouse. But if we would follow the advice given by *A. Fischer* (1897) to study only 1-day-old cultures, then it would be indeed possible to get many uniform, though, of course, very incomplete, results.

McFarland's Textbook on Pathogenic Bacteria (1916) contains another statement of interest in this respect (p. 214):

While the appearances of the freshly isolated organism should be carefully noted, too much stress should not be laid upon them, and before beginning the systematic study of any new organism it should be made to grow for several successive generations upon two or three of the most important culture media. Its saprophitic existence being thus established, the characteristics manifested become the permanent peculiarities of the species.

Some doubt, however, will be justified whether it is, indeed, a correct scientific practice first to change artificially a parasitic organism, which naturally may be very little inclined to grow on our laboratory substrates, no matter how much "importance" we may attribute to them, so that it will assume a different, distinctly saprophitic character, eventually lose its pathogenicity more or less, and to conclude then that now "the characteristic peculiarities of the species" have been demonstrated. It seems, indeed, quite probable that the "domestication" of the bacteria will often alter their morphology, as well as their physiology, relatively to no less degree than it has been the case with the domesticated higher plants and animals.

How deeply the changes caused by continuous artificial cultivation may affect the general appearance of a strain is e. g. clearly reflected in the statement, made by *Migula* (1900) in the foreword to the second volume of his "System der Bakterien," saying that many of the cultures tested by him differed so widely from the original description that they were hardly recognizable. If the advice had been followed which was given by *Adami* (1894), viz., that all systematic studies should be continued not less than a year, and a second description of a so-called new species should be published 12 months after the first one in the same journal, the situation would be much better to-day in many directions. It needs hardly to be emphasized that such work as was done, for instance, by *Bredemann* (1909) with the Amylobacter group, where by persistent "training" of a large number of varieties a general species character is clearly brought out and made more or less permanent, will always undoubtedly have its great value. The peculiarities of aberrant strains, however, should also be carefully studied and recorded. This holds true especially as far as alterations of form and of function occur as the result of natural variability

(5) MORPHOLOGICAL CHANGES DURING THE LIFE CYCLE.

The fifth and last explanation, which eventually may help to solve some puzzling problem concerning bacterial pleomorphism, is the normal development of different forms in the various stages of the complete life cycle of a species.

So far, this point has met with but little consideration, though it will undoubtedly win in importance, as investigations go on. Some valuable material, however, is already available.

As mentioned before (pp. 30, 32), studies upon the variability of the bacteria have shown that, at least in some cases, a distinctly cyclic appearance and disappearance of the "variants" was quite evident. And as far as the so-called involution forms have been considered to be worth studying, the same fact has been noticed, viz. the original form first produces various "involution" forms, which later reproduce the "typical" form, so that eventually a several months' old culture again contains only "normal" cells. Numerous references have been given

on pages 24–28. At the latter place the investigations of *Riemer* (1909) and of *Springer* (1913) have been recorded, which clearly indicate that a distinct periodicity of bacterial growth is noticeable under suitable conditions. It may be added here that the result of our own studies upon the life cycle of the Azotobacter group (*Löhnis* and *Smith*, 1916 *a* and *b*) are in complete agreement with these findings. In soil as well as in nutrient solution a precise succession of the different characteristic stages in the development could be followed not only once, but repeatedly, without making any transfers or any other alteration than adding water aseptically, from time to time, when this became necessary.

The rather unnatural "overstuffed" substrates which are used most frequently in the laboratories will often interfere with such observations. Large amounts of metabolic products may kill the bacteria at an early date, and their presence has also often led to the assumption that they are the cause of the appearance of "variants" and "involution" forms. It is, of course, readily to be admitted that they, indeed, may have exerted some influence, and will often be able to do so. However, as the same or similar alterations are obtainable under quite different conditions, and a successive alternation of "degeneration" and "regeneration" can be easily established on suitable substrates, the natural tendency of the living cells themselves has also to be kept in mind. Moreover, it should not be overlooked that such changed forms, produced apparently under the influence of the metabolic products accumulated in the old substrate, not infrequently retain their peculiar shape very persistently through many transfers on fresh substrates.

In this respect some observations made by *Stamm* (1914) upon the variability of *Vibrio cholerae* are of great interest: 13 typical cultures were kept in water; 6 remained constant, 7 showed profound alterations, and these new forms remained again constant in more than 540 transfers made during 30 months, provided that the transfers were made frequently. Material taken from older cultures, however, either went back to the typical form, or showed further alteration. *Bernhardt* (1915) recorded analogous results with meningococci, typhoid, paratyphoid, septicaemia, and diphtheria bacilli. Daily transfers kept the "variants" obtained from old cultures constant for several generations. As has been demonstrated by *Preisz* (1904) and others, the so-called secondary colonies, frequent especially in old growth of spore-forming bacilli on agar, are also much inclined to produce rather constant strains of different morphological and physiological character. That giant growth and increased resistance of the cells are typical for this new development, is obviously not in accordance with the theory of the dominating influence of the accumulated metabolic products. The "tertiary" colonies, which sometimes develop after another interval, may be accepted as additional indication of the periodicity of growth occurring under suitable conditions.

That the pleomorphism of the bacteria is closely connected with their life cycle was already the opinion of some early French writers, like *Artigalas* (1885), *Cornil* and *Babes* (1890), and *Macé* (1897), who have been quoted on page 8. Two more references may be added here. *Billet* (1890, p. 208) stated that every organism studied by him exhibited "un cycle évolutif bien defini," and *Duclaux* (1898, p. 607) said:

> Il faut prendre un microbe comme un être à générations alternantes multiples et variées, se succédant non suivant une formule regulière, mais suivant les conditions de l'ensemencement. Le lien de l'espèce, c'est la loi qui préside à chacun de ces changements, et la variété des formes et des fonctions n'est pas du tout en contradiction avec l'unite de l'espèce.

In England *Lankester* wrote as early as 1873:

> The existence of true species of bacteria must be characterized . . . by the ensemble of their morphological and physiological properties as exhibited in their complete life histories.

The same standpoint has been taken later by several British authors like *H. M. Ward* (1892, 1910), *Crookshank* (1896), *Walker* and *Murray* (1904), *Dobell* (1911), *Young* (1914), and *Hort* (1915–1917). The changes observed by *Walker* and *Murray* in cultures of *B. typhi*, *coli* and *V. cholerae*, were accepted by them as signs of "an unexpected complexity in the life history of these microörganisms." *Dobell* wrote (1911, p. 484):

> It appears to me probable that . . . the majority of bacteria may possess a wide range of variation in their outward form at different stages in their life histories.

Young emphasized that it is necessary "to try to obtain as many stages of each life history as possible." Of special importance, however, is the following statement made by *Hort* (1917*a*), because it is based on a broad experimental basis:

> Evidence of complex bacterial life cycles is constantly before us, even in ordinary standardized laboratory media, though it may, and often does, require persistent looking for. The truth, in fact, appears to be that we have gone astray in this matter, because we have in the past invoked too easily the theories of contamination, of involution forms, nd of mutation, and have forgotten that the natural environment of bacteria, whether as saprophytes or as agents of disease, is in a perpetual state of flux.

In the older German literature the life cycles of the bacteria have been discussed, of course, more or less hypothetically, by those authors who like *Nägeli, Neelsen, Zopf,* and *Haberkorn,* tried to defend the polymorphistic standpoint against the strict monomorphism of *Cohn* and *Koch.* Some quotations were given on pages 11 and 13. *Nägeli* (1882) was undoubtedly right when he wrote:

> Auf das leichte und subjectiv willkürliche Geschäft der beschreibenden Unterscheidung muss nun erst die eigentliche wissenschaftlich objective Arbeit der exacten experimentellen Untersuchung folgen (p. 139). Durch Züchtungen, die hinreichend lange unter den verschiedensten äusseren Umständen fortgesetzt werden, ist zu bestimmen, welche Formen sich in einander überführen lassen und welche nicht (p. 138).

The same holds true concerning the following statement made by *Zopf* (1883, p. 47):

> Eine Systematik im Sinne der anderen Pflanzengruppen ist für die Spaltpilze zur Zeit insofern nicht möglich, als es an einer entwicklungsgeschichtlichen Durcharbeitung des Gebietes noch gänzlich fehlt.

The curious change in *Brefeld's* view, which led him (1908) to the assumption that it is a priori erroneous to undertake any investigations upon the life history of the bacteria, though he, too, had advocated such studies at an earlier date (1881), is a good example of the blighting effect exerted by the rigid monomorphistic dogmatism propagated by the orthodox followers of *R. Koch.*

Even *F. Cohn* has once (1872*b*, p. 130) emphasized the necessity of thorough investigations upon the life cycles of the bacteria (see quotation on p. 11), though he abandoned later this standpoint more and more. But it is still more surprising that an author like *Fraenkel* (1891), who did not hesitate to declare any type of growth or any reproductive organ which was not approved by *R. Koch* as an entirely superfluous, "illegitimate," degenerate by-product (see quotation and critique on p. 27), nevertheless admitted that no definite arrangement of the system of the bacteria could be made, because:

> Der nötigen entwicklungsgeschichtlichen Durcharbeitung entbehrt das ganze Gebiet noch zu sehr, als dass ein solches Vorgehen schon am Platze wäre (p. 13).

The more correct opinion, which during the last two decades has gained some ground among German and Austrian bacteriologists, has naturally evoked new interest in such studies. It was especially the Austrian authors *W. Winkler* (1899), *Mencl* (1905), and *Fuhrmann* (1906–1913) who recommended a renewed close study of the complete life cycles of the bacteria and themselves contributed some important findings from this field.

Although the full discussion of the data secured by such investigations upon the life history of certain species will better find its place on the following pages, a short compilation of the names of the authors and of the organisms, studied by them, may be inserted here. It is of great interest for three reasons: First, practically all these studies have been made quite independently and the good agreement of the results obtained is, therefore, of increased importance. In the second place, it is of great value that representatives of all groups of bacteria have been tested and analogous results have been recorded with all of them. In the third place, it becomes evident that the necessity of such studies has been felt quite generally; among the authors who have done such work practically all nationalities are represented.

The careful studies of *Thiercelin* (1899–1903) on the various developmental stages of his Enterococcus will prove helpful for further investigations upon the streptococci. *W. Winkler* (1899) obtained very important data with *B. coli, fluorescens, aquatilis,* and with a yellow, nonspore-forming rod (probably *Bact. herbicola*), which he rather incorrectly named *B. mesen-*

tericus aureus. *Hauser's* early work upon his Proteus (1885) furnishes a practically complete picture of the life history of this group of organisms. *Fuhrmann* (1906–1908) studied the life cycles of his *Pseudomonas cerevisiae*, several Fluorescentes, and of some other rods. *Almquists* investigations (1893–1917) were especially concentrated on the typhoid bacillus and the cholera vibrio. The latter had also been the object of the little known work of *Ferrán* (1885) and of *Dowdeswell* (1889–1890). *Finkler* and *Prior* (1885) gave a fairly complete report upon the life cycle of their vibrio, isolated from Cholera nostras. *Albrecht* and *Ghon* (1900), *N. K. Schultz* (1901), as well as *Rowland* (1914), have furnished valuable contributions to the complete knowledge of the life history of *B. pestis*. *Rosenbach* (1909) did the same concerning the bacteria causing erysipeloid, rouget and septicaemia of mice. The life history of some organisms closely related to Friedländer's Pneumonie bacillus was described by *Bordoni-Uffreduzzi* (1888) and by *Jehle* (1902). *Johan Olsen* (1897) investigated the life cycle of *B. mycoides* and of other spore-forming bacilli. The glanders organism has been studied along similar lines by *Carpano* (1913), the leprosy organism by *Lutz* (1886), *Barranikow* (1900), and by *Kedrowski* (1901), the tubercle bacillus by *Schroen* (1886–1904) and by *Maher* (1910–1913) and the Corynebacteria by *E. de Negri* (1916), and by *Bergstrand* (1918). *Krzysztalowicz* and *Siedlecki* (1908), as well as *McDonagh* (1912–1913) made the life history of *Spirochaeta pallida* the object of their investigations. In *Meirowsky's* "Studien über die Fortpflanzung von Bakterien, Spirillen und Spirochaeten" (1914 *b*) for the first time representatives of very different groups (*B. tuberculosis, leprae, paratyphi, enteritidis*, various spirilla, and spirochaets) have been made the object of a thorough comparative research. Of equal or even greater importance are the investigations of *Hort* and his collaborators (1915–1917), who worked with meningococci, typhoid, paratyphoid, dysentery, and colon bacilli. And in our own experiments upon the life cycles of the bacteria (1916) representatives of practically all groups of bacteria, except mycobacteria and spirochaets, have been included.

Fig. 1 on Plate A taken from our first paper (*Löhnis* and *Smith*, 1916 *a*) shows in a schematic arrangement the rather complicated life cycle of *B. azotobacter*, and a glance at the two Tables II A and II B, taken from the same paper (pp. 683 and 689) and revised with regard to some additional findings mentioned in our second preliminary communication (1916 *b*), reveals at once the important fact that essentially the same types of growth occur in the life cycles of all different kinds of bacteria.

TABLE II A.—*Types of growth observed with 24 cultures of Azotobacter.*

[The laboratory numbers of the cultures are given at the head of the columns.]

Types of growth. (For explanation of letters see Table II B.)	Azotobacter Chroococcum stock cultures.		Azotobacter Beijerinckii.				Azotobacter vinelandii.	Azotobacter vitreum.	Azotobacter chroococcum stock cultures.			Azotobacter Beijerinckii.	Azotobacter chroococcum.	Azotobacter Beijerinckii.	Azotobacter vinelandii.	Azotobacter chroococcum stock cultures.				Azotobacter chroococcum new isolations.				
	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
B	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
C	+	+	+	+	+	..	+	+	+	+	+	+	+	..	..	..	+	..	..	+	+	+	+	+
D	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
E	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
F	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
G	..	+	..	+	..	+	+	..	+	+	+	+	+	+	..	+	+	+	..	..	+	..	..	+
H	+	..	..	..	..	..	+	+	..	..	+	..	+	..	..	+	+	..	..	+	+	+	+	+
I	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
J	..	..	..	..	..	..	..	..	..	+	+	..	+	..	..	..	+	..	..	..	+	+	..	..
K	+	+	+	..	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
L	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
M	..	..	+	..	..	..	..	..	..	+	+	..	+	..	..	..	+	..	..	..	+	+	..	..

TABLE II B.—*Types of growth observed with 18 representative bacteria.*

[The laboratory numbers of the cultures are given at the head of the columns.]

Types of growth.	B. subtilis.	B. lactis niger.	Tyrothrix tenuis.	B. danicus.	Bact. pneumoniae.	Bact. radiobacter.	Bact. denitrificans agile.	Bact. radicicola.	Bact. fluorescens.	Yellow bacillus.	Planosarcina ureae.	Sarcina flava	Midr. candicans (soil).	M. (candicans milk).	Salt Lake spirillum.	Ocean spirillum.	Streptoc. lactis.	Bac. bulgaricus.
	31	32	33	34	35	36	38	39	40	41	42	43	44	45	46	47	48	49
A (large globules and ovals)	+	....	....	+	+	....	....	....	+	+	+	+	+	+	....	....	+	....
B (thick walled forms of type A)	+	+	+	+	+	....	....	....	+	+	+	+	....	....	....	....	....	+
C (granular decomposition of A, B, L, M)	+	+	+	+	....	....	....	....	....	+	+	+	+	....	....	....	....	+
D (symplasm)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
E (small globules and ovals)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
F (small rods and threads)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
G (slime threads with cocci)	....	+	+	+	+	+	+	+	+	+	+	+	....	....	....	+	....	+
H (granular decomposition of F and of spores)	+	+	+	+	+	+	+	+	+	+	+	....	+	....	....	....	....	+
I (regenerative bodies)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
J (normal cells developing inside)	+	....	+	+	....	....	....	....	....	+	....	....	....	....	....	....	....	....
K (budding gonidia)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
L (large rods and threads)	+	+	+	+	+	....	....	+	+	+	+	....	+	+	....	....	+	+
M (cells with pointed ends)	....	+	....	+	....	+	+	+	+	....	....	+	+	+	....	....	+	+
N (starlike growth)	+	+	....	....	+	+	+	+	+	+	....	....	+	+	+	....	+	+

The detailed discussion reserved for the following pages will bring additional proof that a fairly correct insight into the little-known life history of the bacteria is obtainable at the present time, provided that those observations are carefully considered which practically always have been laid aside because they were incompatible with the prevalent doctrine, and in their isolation they had not sufficient weight to command attention and to instigate renewed experimental investigations.

It is beyond doubt that such investigations will lead to an incomparably better knowledge of the real morphology and physiology of the bacteria. The present situation in bacteriology is very much like that confronted by *Tulasne* (1851) in mycology, in regard to whose work *De Bary* (1884, p. 129) said:

> Anknüpfend an wenige und immer wieder zurückgedrängte Beobachtungen unternahm er zu zeigen, dass die Formspecies der bisherigen Mycologie in vielen Fällen nicht für sich allein Speciesrepräsentanten sind, sondern dass eine solche Formspecies mit anderen dem Entwicklungskreise einer wirklichen Species angehören kann.

What has been written by *Sachs* (1875, p. 214) about the algae holds equally true to-day concerning the bacteria:

> The discovery of alternation of generations and polymorphism in some sections justifies the supposition that certain forms not as yet accurately known may be merely conditions of development of unknown cycles of forms, although hitherto considered distinct species and genera.

That a complete knowledge of bacterial ontogeny is absolutely necessary for securing a well-founded insight into the phylogeny of these organisms is beyond question, since *Haeckel* (1876) has shown how the development of the tribe is reproduced in the life history of its members. *Hueppe* (1886, p. 41, 149), *Kruse* (1896*c*, p. 492), and *Fuhrmann* (1906) have already emphasized the importance of this fact in regard to bacteriology.

(c) THE STUDY OF PLEOMORPHISTIC PROBLEMS.

It goes without saying that in every case where morphological and physiological alterations of the bacteria are made the object of more or less thorough studies all five explanations discussed on the foregoing pages will have to be taken under consideration. Thus far dogmatism and standardization have acted too frequently as some kind of "theoretical blinders" in bacteriological investigations. Moreover, the practical aims of most of the work done, and the resulting impossibility to follow up interesting new observations in a correct scientific manner, have also to be borne in mind as important reasons why the whole situation is still so unsatisfactory. To discard indiscriminately all unexpected cases as "contaminations" and "involution forms" is a practice which certainly should not be followed more frequently than is absolutely necessary.

To decide correctly which explanation will be applicable in one or the other case is not always easy. It may be done either by continuous, direct, microscopical examination or by isolating and studying single-cell cultures, or by comparing results of suitably arranged and sufficiently extended parallel experiments. Every one of these three ways has its advantages and disadvantages; none of them is principally superior to the others.

The continuous direct microscopic examination has been repeatedly declared to be the only manner in which convincing results can be secured. However, this categorical statement is more the outgrowth of unscientific dogmatism than the result of experimental experience. In some special cases direct continuous observation is, indeed, highly recommendable, or even indispensable. Formation and germination of spores and of other reproductive organs, budding and branching, the occurrence and meaning of apparently sexual processes, for instance, are some points which will be studied advantageously with the living material under the microscope. In other cases other ways will be preferable for securing conclusive results. What *De Bary* (1884, p. 137) said is, of course, indisputable:

Das erste Postulat einer morphologisch-entwicklungsgeschichtlichen Untersuchung ist der Nachweis der organischen Continuität successiver Entwicklungszustände.

But it is very disputable whether the highly unnatural conditions prevailing in a hanging drop or agar block preparation on the stage of a microscope are best suited to bring out the normal developmental stages characteristic for the bacterial life under natural conditions.[1]

It should also not be overlooked that many of the older publications upon the pleomorphism of the bacteria have been the result of patient continuous microscopic studies. And yet practically all of them have been discarded as not convincing, some of them certainly with good reason. The latter holds true, e. g., for many of *Hallier's* discoveries. But even the reports of such well-trained investigators like *Rindfleisch* (1872), *Klebs* (1875 *a* and *b*), and *Cienkowski* (1877), who unanimously stated that they directly observed the change of coccus to rod-forms and vice versa, were later not accepted as conclusive proof against the monomorphistic dogma: that a coccus is always a coccus and a bacillus a bacillus, "and any evidence which may be presented to the contrary is based upon untrustworthy methods of observation" (*A. C. Abbott*, 1902, p. 51). *Zopf's* fundamental researches upon the pleomorphism of the bacteria (1881) were all based on direct continuous observation, and that *Winogradsky's* opposite findings, (1887–1888), which by monomorphistic writers have always been quoted as final evidence against *Zopf's* work, though they were obtained with the same method and with impure cultures, too, that they, in fact, are by no means very accurate and convincing, has been sufficiently shown by *Zopf* (1895) in a special reply, which hardly ever has been quoted. That it is possible to keep a form constant for some time under constant conditions, as *Winogradsky* has shown in these experiments, is beyond question. Millions of cultural experiments made according to standardized methods have confirmed this fact. But it is equally beyond question that such highly artificial experiments, in which no attention is paid to the innumerable modifying influences of time and environment, constantly present and active in nature, can at best be accepted only as part of the truth. As early as in 1880 *Neelsen* emphasized quite correctly, after having discussed the various difficulties which may reduce the value of experiments based on direct observations, especially in the case of motile organisms:

Endlich aber wäre selbst nach glücklicher Überwindung aller dieser Schwierigkeiten noch nicht viel gewonnen; man würde zwar ein Bild des Entwicklungsganges haben, wie er in einem bestimmten, sich gleich bleibenden Medium abläuft, aber dadurch keine Kenntnisse erlangen von den Modificationen dieses Cyclus, respective den anderen Formen des Wachstums und der Fortpflanzung, wie sie in Medien von anderer und wechselnder Zusammensetzung vorkommen.

Gruber (1885) and others have published similar critiques. *Metchnikoff* (1889 *b*) wrote against *Winogradsky* that the continuous observation in the living state can not be considered to be a "conditio sine qua non":

Il ne faut pas oublier qu'il existe un grand nombre de parasites dont l'évolution ne peut presque pas être étudiée sur le vivant et dont le developpement est néanmoins suffisement connu.

[1] In 1874 *Billroth* wrote in this respect: "Man würde auf diesem künstlichen Wege nur die unvollkommensten, dürftigsten Formen erzeilen, welche von den ausgebildeten so verschieden sind wie Hafer im Zimmer auf feuchte Watte ausgesäet von üppigem Hafer auf gutem, cultivierten Feldboden."

More recently *Meirowsky* (1914 *b*, p. 84) has pointed out that especially in the case of the protozoa nobody has been able to follow the whole life cycle of any species by continuous direct microscopic observation:

> Auch hier hat kein Auge an einem Exemplar den Zyklus ablaufen sehen, sondern man hat auf die Entwicklung aus verschiedenen, auf einander folgenden Bildern geschlossen.

The use of single-cell cultures has also been strongly recommended more recently, especially for solving problems in bacterial variability. A paper by *Cole* and *Wright* (1916) upon the application of the pure-line concept to bacteria is a characteristic example how easy it is to put forth such purely theoretical demands without furnishing any experimental support. They believe that "pure lines" would show great constancy, but it is not mentioned in their paper that actually all experiments which have been made so far have shown without any exception that single-cell cultures give exactly the same results in pleomorphism and variability as do pure cultures obtained from plates. The investigations of *Kowalenko* (1910), *Baerthlein* (1911), *Bernhardt* (1912), *Nyberg* (1912), *Penfold* (1912), *Fürst* (1914), *Rosenow* (1914), and of *Almquist* (1917) have brought out this fact sufficiently. *Baerthlein*, *Bernhardt*, *Nyberg*, *Penfold*, and *Almquist* confirmed their own experiments, but it is of special interest that *Fürst* was able to confirm with his single-cell cultures of the *Finkler-Prior* vibrio the results obtained by *Firtsch* (1888) about 25 years earlier. The same holds true concerning *Rosenow's* new experiments upon the streptococci, as a counterpart to those of *Kruse* and *Pansini* (1892), and in regard to *Kowalenko's* Coli studies, as compared with those of *M. Neisser* (1906) and *Massini* (1907).

That by no means every colony appearing on the plate represents the pure progeny of a single cell is an indisputable fact. But it is equally certain that repeated plating, controlled by careful microscopic studies, and eventually supplemented by passage cultures in other substrates, will finally furnish exactly the same "pure lines" as any of the single-cell methods. It is difficult to understand why a method, which always has been accepted as quite reliable as long as the results obtained with it have been in accordance with the monomorphistic theory, suddenly should become so highly suspicious, as soon as some conflict arises between preconceived ideas and the facts before our eyes.

It is not to be denied that the study of single-cell cultures will occasionally prove very helpful, or even necessary. All methods thus far devised for this purpose, however, have their conspicuous disadvantages. The frequently very unsatisfactory growth of the isolated cells is one of them. In *Barber's* (1907) experiments, e. g., 40–70 per cent of *B. coli*, otherwise so readily propagating on all substrates, failed to grow. *Fürst* (1914) succeeded with *V. proteus* in only 10 per cent of all cases. That the chances for contamination are considerably increased should also never be forgotten.

Generally, therefore, the standard methods which otherwise have proven their reliability during the last decades will also have to be considered in the first place for conducting experiments upon the life history of the bacteria. If we only abstain from the unscientific practice to discard, without adequate testing, every culture showing some unexpected development as "contaminated" or as containing "merely involution forms," and every slide as "not sufficiently clear" which shows something more than the monomorphistically trained eye is inclined to see, those methods will usually prove quite satisfactory, provided that a sufficient number of parallel experiments is suitably arranged, long enough continued and several times repeated.

This latter point has been strongly emphasized by *Gruber* as early as in 1885, when he first attacked the monomorphistic dogma then proclaimed by *R. Koch's* followers (with "religious fanaticism" as *Gruber* says). His own experiments showed him that globular, rod-like and spiral forms are merely types of growth, not distinctive marks of species and of genera. Changes from one form into the other were observed with pure cultures as often as the experiments were repeated, and it was always possible to retrace the intermediate steps to the starting point. In his "mutation" studies *Baerthlein* (1911) also accepted the uniformity of the results obtained in a great number of parallel experiments as full proof of their validity. *Nyberg* (1912) equally pointed out that it would be entirely improbable to

assume, that accidental contaminations would cause the uniform results which he secured with 140 strains of various lophotrichous rods, all producing the same types of pleomorphous colonies. *Bernhardt* (1915, p. 219) made the following remark upon this subject:

Wer zahlreiche derartige Umwandlungsversuche an verschiedenen Bakterien Monate hindurch selbst verfolgt und sich immer wieder von neuem davon überzeugt hat, dass bei jeder Bakterienart die Veränderungen doch immer nur in ganz bestimmter Richtung erfolgen, wird kaum je Schwierigkeiten haben, die Verunreinigungen, die selbstverständlich auf alten Platten nicht ausbleiben, als solche zu erkennen.

That experiments of short duration are hardly of any value has been discussed before (see the quotations from *Adami* on p. 33, and from *Stamm* on p. 34). The very great persistency exhibited by some strains, as observed, e. g., by *Stamm*, may occasionally test the patience of the investigator very much. However, appropriate experimenting usually will eliminate difficulties arising from this source.

It has also been mentioned before that not infrequently strict adherence to monotonous standardized laboratory methods has hindered, and will perhaps further delay such progress as should and could have been made in bacteriology long ago. There is unquestionably a very wide gap between the highly artificial conditions under which the pure cultures are often compelled to live in the laboratory and the actual situation the bacteria are confronted with in nature. In this respect it should be borne in mind that various strains of the same species of bacteria when recently taken from their natural habitat not only differ more or less from strains of the same species kept for some time in "solitary confinement" in the laboratory, but they also show very often considerable incongruencies when compared with each other. Sets of accumulation experiments, as recommended by *Beijerinck* and others, demonstrate this fact conclusively. The interesting results obtained by *H. M. Ward* (1895 *a*) and by *Stamm* (1914) in their studies upon the development of bacteria in water, also show clearly the sometimes deeply alterating influences of a more natural surrounding. In our first preliminary paper upon the life cycles of the bacteria (1916 *a*, p. 685) it was pointed out that it was very easy to obtain full insight into the complete life cycle of *B. azotobacter* by inoculating all the strains on hand (numbering 22) into their natural substrate, viz., into soil. The important results obtained by *Almquist* in regard to the life cycles of pathogenic bacteria are also mostly due to a studious application of the conditions to which these organisms have to adapt themselves when living naturally as saprophytes.

A comparison of the different influence of the natural and of the more or less artificial conditions as given in the laboratory would be rather incomplete, however, if the effect caused by symbiotic interaction would not find due consideration. That physiological activities can be, and often are, deeply altered, when bacteria are growing in symbiosis has been repeatedly noticed. Details are to be found in the publications of *Cornil* and *Babes* (1890, Vol. I, pp. 229–237), *Th. Smith* (1894), *Kruse* (1910, p. 168), and others. But so far comparatively few observations have been recorded which indicate that in morphological studies equally unexpected results may be caused by symbiosis. *Lorenz* (1892) obtained a clearly actinomyces-like growth of *B. erysipelatos suum*, when he inoculated this organism in a filtered culture broth of *B. suisepticus*. In gelatin, as well as in the animal, the bacilli reverted promptly to their "typical" appearance. But more recently *Rosenbach* (1909) has demonstrated that the complete life cycle of the organism named, as well as of those closely related to it (erysipeloid and septicemia of mice), embraces, indeed, such an actinomycotic phase. *Metchnikoff* (1894) found large club and dumb-bell-shaped forms with lateral buds in a cholera culture, which contained a white coccus. From other researches, especially from those of *Dowdeswell* and of *Stamm*, it is known that these forms, too, belong to the normal life history of *V. cholerae*. *Metchnikoff* points out:

La constance de cette modification indique une influence particulière du coccus blanc sur les fonctions du vibrion.

Kurth (1898) discovered that the diphtheria bacillus is much inclined to change its appearance whenever other organisms are present. Symbiosis with *Streptococcus lanceolatus* caused the development of very short forms, which were hardly discernible from the pneumococci

themselves. Ten years later *Smirnow* (1908) made exactly the same observation, from which the following conclusion was drawn:

> The change in morphology of the Klebs-Loeffler bacillus to a coccus and the return to its bacillary form is interesting, as it indicates the possibility that bacteria may change their morphology under certain favorable or unfavorable conditions.

Similar changes were also observed in these experiments when the two organisms were cultivated in "double test tubes" (one within the other), so that only the metabolic products could penetrate into the other culture and no streptococci could be mistaken for diphtheria bacilli, and vice versa. As practically all cases of diphtheria present mixed cultures of *B. diphtheriae, streptococci,* and other symbionts, the importance of these findings is evident, especially when combined with the fact that several entirely independent observations have been recorded, where nothing but coccoid forms were found in cases of true diphtheria (*Dale,* 1910; *Balfour,* 1911 *d*). Some observations of *Heinemann* (1917), on the other hand, clearly indicate that also in this case the "illegitimate" forms are, in fact, part of the normal life cycle of this species, and analogous findings have been made with diphtheroid organisms by *Walker* and *Adkinson* (1917), as well as by *Mellon* (1917).

The olive-tubercle organism studied by *Petri* (1907) quickly assumed characteristic "involution" forms when grown together with *Ascobacterium luteum.* The changed forms remained also in this case capable of further propagation.

Babes (1893) secured development of the fusiform bacilli found in cases of scurvey, as well as in the normal mouth, only in such agar where streptococci had been grown before, and here the bacilli also produced curved threads "longer and thinner than cholera bacteria." *Proca* (1908) found anew that *B. fusiformis* grows much better in symbiosis with *B. subtilis* or *streptococci* than alone. The typical spirochaete-like spiral forms with pointed ends found by other investigators in pure cultures of *B. fusiformis* appeared readily in broth cultures of the symbionts.

The highly interesting diphtheria-like forms (club-, dumb-bell-, spindle-shaped, etc.) first seen by *Babes* (1895) in pure cultures of the streptococci were also produced much more abundantly by the so-called *Bact. Guentheri* (*Streptococcus lactis*) when grown in symbiosis with *B. putrificus* (*A. Wolff,* 1908). *Lorenz* (1909) noticed that the very pleomorphous streptococcus, isolated by him from horses afflicted with "Brustseuche," gave a distinctly Streptothrix-like development when cultivated together with an Aspergillus. *Rosenow* (1914), too, emphasizes the importance of symbiotic effects in his report on the transmutations within the Streptococcus-Pneumococcus group.

That occasionally such experiments with mixed cultures may be of great advantage in solving special problems in regard to the life history of one or the other organism may be seen from the following experience. One of my two Azotobacter strains, which first had passed over into thin spore-forming rods, reverted readily back to the characteristic large round Azotobacter type when cultivated under suitable conditions (in mannite soil extract). The other, however, remained absolutely stable despite repeated transfers. Considering the fact that in nature Azotobacter always is to be found in symbiosis with *B. radiobacter,* this organism was added with the result that in very short time the large form reappeared, though it turned out to be very unstable after renewed isolation (*Löhnis* and *Hanzawa,* 1914, culture No. 6, figs. 15–19). In another experiment made by *Kuntze* (1904) a similar case has been observed. *B. oxalaticus,* whose pure cultures when kept for some time on artificial substrates quickly assumed the "normal" Subtilis-like appearance, looked very much like Azotobacter when growing in symbiosis with the so-called *B. denitrificans agilis,* which is probably a denitrifying variety of *B. radiobacter.* Moreover, as early as in 1884 *DeBary* (p. 503) reported that his *B. Megaterium* grew in rows of large cocci, which also broke up into single cells, and which never produced spores (all this like Azotobacter) when this organism was kept in mixed culture with a small bacterium whose identity has not been established, but that they reverted to the typical spore-forming bacilli when separated from this symbiont.

The remarkable uniformity of the results obtained in these three cases may be accepted as another indication that it seems to be recommendable for a correct study of the complete life

history of the bacteria to take under due consideration also such biological influences, permanently active in nature, in addition to the many physical and chemical factors which may often cause important reactions on the side of the bacteria. These, perhaps, never would be discovered if we continue to adhere too closely to the ordinary laboratory methods.

It is beyond question that our knowledge of the true life history of the bacteria is still very inadequate, and that we are far from knowing all facts about them which we should know. That the ascertainment of these data is absolutely necessary before any correct decision can be reached concerning the true character and the systematic position of the various species of the bacteria has been emphasized by numerous authors, like *Klebs* (1875*b*), *Davaine* (1876, p. 20), *Gruber* (1885), *Hueppe* (1886, p. 84; 1891, p. 27), *Cornil* and *Babes* (1890, Vol. I, p. 18), *R. Koch* (1890), *Beijerinck* (1898), *H. M. Ward* (1910), and others. With regard to *Zopf's* classification, which at least tried to make use of what was known at that time upon the life history of the bacteria, *H. M. Ward* made the following remarks in his important paper "On the Characters, or Marks, Employed for Classifying the Schizomycetes" (1892), which also at the present time deserves our attention:

> *Zopf's* classification, admirable as it is in many respects, is difficult to work in practice, because it is necessary to have all the stages of development before we can decide on the position of a species; at the same time it should be noted that in this very respect it is far ahead of the merely tabular classifications, used for hurriedly determining the name of a form, as a good flora is ahead of a mere museum catalogue of plants . . . It is, in fact, just in respect of this particular attention to all the facts in the development of the species that *Zopf's* classification is scientifically so far in advance of his predecessors . . . The matter of difficulty of application can not be urged as a reason for desisting from obtaining and recording all that can be discovered regarding an organism . . . On the other hand, pathologists, hygienists, chemists, etc., often do not care, what vagaries the organism exhibits, so long as they can recognize it when they meet with it. As a matter of experience, however, it is just these vagaries that bring about the sources of error which beset them on all hands, and hence they are equally interested with the botanist in having them cleared up, and explained.

It has been pointed out before, that it is a fundamental mistake to assume that the acknowledgement of the pleomorphous character of the bacteria be equivalent to an attempt to obliterate all bacteria species. That many of the so-called species, introduced into the literature, often by the dozens, by quite inexperienced recruits in bacteriology, will have to disappear is of course, beyond question. Such an elimination of entirely worthless ballast, however, has, nothing at all to do with a cancellation of well described species. The narrow limiting of species, as advocated by *F. Cohn, R. Koch, Winogradsky, Migula* and others, should have been abandoned long ago, and, as was shown by numerous quotations, it has indeed already met with much well justified opposition. *Jordan* (1909, p. 339) aptly remarks:

> The features that should characterize a bacterial race or species have not yet been established, and until some consensus of opinion on this point has been reached, discussion of specific identity is futile."

The following lines by *E. F. Smith* (1905, p. 155) are equally worth quoting in this connection:

> Many names have been given unaccompanied by any proper description of the organism . . . To found, for example, a new species of rabbit on the observation that a small jumping animal about the size and shape of a rabbit has congregated in certain turnip fields and caused great damage, and apparently had destroyed no other plants, would only serve to provoke a smile or to raise a doubt as to the author's mental condition, and yet descriptions equally worthless are not at all uncommon in systematic bacteriology.

A still earlier statement made by *Hill* (1902*a*) has also lost nothing of its validity:

> It is easy to say that the whole subject needs much development before consideration of the names to be employed is necessary. Names, indeed, can not be intelligently selected until the facts themselves are thoroughly established and correlated.

So far, the variability of the bacteria alone has been more closely considered in connection with these problems, and it was usually from this point of view that the establishment of well-defined groups has been advocated by European and American authors. That truly natural species can be founded, however, only after a much more thorough knowledge of their complete life history will be available, hardly needs to be emphasized. The details discussed on the following pages will help to make clear how much work remains to be done along these lines, and what new insight into the natural relationship among the bacteria may be gained from

such studies. Moreover, these facts in their entirety furnish a welcome support to the following statement made in our first preliminary report on this subject (1916*a*, p. 677):

> The development of the bacteria is characterized not by the irregular occurrence of more or less abnormal forms, but by the regular occurrence of many different forms and stages of growth, connected with each other by constant relations.
>
> Unquestionably many so-called species, frequently described in the most superficial manner, will have to be cancelled, because they merely represent fragments of the life cycles of other bacteria. Good species, on the other hand, will not only keep their position, but they will receive a much more complete and sharper definition than they now have.

2. MORPHOLOGY OF THE DIFFERENT GROUPS OF BACTERIA.

(a) COCCI.

That the old form-genera Micrococcus, Sarcina, and Streptococcus each comprise severa groups of organisms which will present themselves as natural genera as soon as their full life cycles will have been studied is already clearly indicated by several observations recorded thus far. That, however, such highly variable marks as pathogenicity and pigment production can not be considered to be of fundamental value in this respect has been discussed. (Concerning pigmentation of micrococci see especially *Neumann*, 1897; in regard to pathogenicity of micrococci, *Geisse*, 1914; of streptoccocci, *Heinemann*, 1915, and upon carbohydrate fermentation of streptococci, *Broadhurst*, 1915, and *Henrici*, 1916.) It is quite true that Micrococci as well as Streptococci exhibit a rather well recognizable general character. But there is a number of cases where it is difficult or even impossible to decide clearly whether the organism should be classed as a Micrococcus or as a Streptococcus. When I (1907) tried to arrange the numerous so-called species of lactic acid bacteria and their relatives in some fairly well defined groups, I had to dwell upon this particular point. Soon afterwards *Babes* (1908) showed experimentally that even an otherwise typical *Staphylococcus aureus* may occasionally assume the morphological appearance of a Streptococcus. To the same author we owe the first distinct results concerning the close relationship existing between Streptococci and the diphtheria group (*Babes*, 1895). The analogous relations connecting micrococci and actinomycetes have been more recently emphasized by *Beijerinck* (1914*a*). Comparatively the most conspicuous heterogenicity is noticeable among the Sarcinae. Some of them are undoubtedly merely types of growth of micrococci. (See *Lehmann* and *Neumann*, 1912, p. 198; *Löhnis*, 1907, p. 146.) Others, however, evidently belong in the life cycle of typical rods, especially of spore-forming bacilli.

That most of the so-called Micrococcus species created by *F. Cohn* were no micrococci at all has been mentioned on page 11. And it has also been pointed out that statements made by *Fraenkel* and *Pfeiffer* (1895), *A. C. Abbott* (1902), and others, maintaining that an absolute constancy of the cell form is to be found with the micrococci, are in open conflict with numerous well established facts.[1])

It may happen, of course, that one or the other strain will be temporarily constant, sometimes even for a comparatively very long time. In our experiments, e. g., two strains of *Micrococcus candicans*, one from Russian soil, the other from evaporated milk, exhibited very readily and in a quite uniform manner the characteristic stages of their life cycle, of which some forms are reproduced in figs. 1–4, Pl. I, while on the other hand a *Micrococcus luteus* was quite irresponsive; but a careful search revealed in this case, also, at least some inclination to form the large club forms characteristic for this group. The use of salted substrates has helped *Matzuschita* (1900) to get the peculiar rod-like forms with *Micrococcus rubefaciens* and *M. flavus*, as shown in figs. 5 and 6 on Pl. I [2], while *Maassen* (1904) and *Péju* and *Rajat* (1906*e*) did not see any alteration of the micrococci tested on similar substrates. The yellow *Kokkobacillus*

[1] In the explanation to Table I of their "Atlas," *Fraenkel* and *Pfeiffer* say: "Mit grosser Zähigkeit halten die Mikrokokken unter allen Umständen an der ihnen eigentümlichen Form fest, und mit Recht werden sie deshalb auch als der beste Beweis für das vielumstrittene Gesetz von der Constanz der Form bei den Bakterien angesehen. Äussere Einflüsse jeder Art bleiben dieser Eigenschaft gegenüber vollkommen machtlos, und ein echter Mikrokokkus erscheint stets nur in seiner streng kugligen Gestalt."

[2] In these two cases the rod-like forms were abundant, whereas with *M. luteus, candicans, aurantiacus, coronatus, flavus desidens, aërogenes Sarcina lutea*, and *agilis* only occasionally stretched forms became visible among the cocci.

zymogenes, isolated by *Biedert* (1885) from saliva, grew as a coccus, rod, or thread. Some of the straight forms contained coccoid bodies, whose further development was not observed. The yellowish "Mikrokokkus B" of *Malapert-Neufville* (1886, p. 57) from water showed at first typical globular forms, but stretched later into distinct rods which in their turn broke again into micrococci. The yellow *Micrococcus subnormalis* of *Hopkins* (1898) from the human mouth grew at first on agar, gelatin, broth, and potato as a rod, later as a coccus; on serum, however, it showed the form of a coccus from the start. Whether these three organisms were identical or not must naturally remain an open question, though it seems quite possible. The photographs accompanying *Hopkins'* paper are very much like our pictures of *M. candicans*. Even branching and budding are clearly visible, although they were not mentioned by the author. Changes from cocci to rods, diphtheroid and yeast-like forms also have been recorded by *Young* (1914).

Best known, however, are the transformations exhibited by *M. melitensis*, which species, on account of its morphological instability, has been transferred more recently by some authors to the bacilli. *Durham* (1898), who published the first fairly correct description of this organism, found out that both agar and broth gave exclusively micrococci when kept at 37° C, while at 18–20° after a few weeks almost exclusively bacilli were visible, about two to four times longer than broad, and sometimes curved. But brought back to 37° they reverted to "the ordinary coccus form in pure culture." *Babes* (1903) gave another description and good pictures of *Micrococcus melitensis*. Part of the forms, especially those of club-like appearance, resemble very much certain pseudo-diphtheria bacilli. According to *Babes'* opinion, relations may exist with bacteria occurring in bronchitis and whooping cough, perhaps also with the influenza bacillus. *Günther* (1906, p. 771), as well as *Lehman* and *Neumann* (1912, p. 231), consider the organism to be a coccus which occasionally produces rod-like, clubbed, and other forms. *Jordan* (1916, p. 416) calls it *Bac. melitensis*. The picture accompanying his description, reproduced as figure 7 on plate I, makes an interesting counterpart to the rod-like forms of other cocci (figs. 2–6); in the center of figure 7 cocci are seen to bud out of a rod-form, and very similar things are visible in figure 8. The rods exhibit in all these cases the same irregular appearance, as is common with the Mycobacteria (especially with those of the diphtheria group). *Eyre* (1907) is strongly opposed to the idea of placing *M. melitensis* among the bacilli. He thinks that all bacillary forms are either stretched cocci or irregular "involution" forms. His figure 2 shows all types pictured in our photographs of *M. candicans*. Exactly opposite is *Saisawa's* (1911) standpoint. This author is certain that the organism is a typical short rod, not a coccus. In his photographs cocci budding forth from rods are again very conspicuous, but in the paper itself nothing is said about this interesting fact. *Evans* (1918) made the interesting discovery that six strains of *M. melitensis* behaved morphologically and biochemically, as well as in the agglutination test, as did *B. abortus*.

The organism introduced by *F. Cohn* (1872) as *Micrococcus phosphoreus* is at present classified, probably by all authors, as *Bacterium phosphoreum*. According to *Molisch* (1903, 1904, p. 60) typical cocci are exclusively formed on salted agar, while in salted gelatin all kinds of irregular rods, clubs, etc., become visible. On agar and potato cocci were found in the beginning, which were later supplanted by rods, clubs, and branched forms.

F. Cohn's Micrococcus cyaneus has been studied anew by *Beijerinck* (1914 *a*) and renamed *Actinococcus cyaneus* on account of its relationship to Actinomyces. It grows usually blue, but red in acid-producing varieties, and white when reinoculated from old material. According to the Dutch author the new genus Actinococcus should embrace all micrococci which exhibit clearly Actinomyces-like characters, and it should be placed in the neighborhood of Corynebacterium, Mycobacterium, and Actinomyces.

In this connection, and in addition to the confirmative results mentioned above, the old observations of *Rabe* (1886) concerning his *Micrococcus botryogenus* regain new interest. Growth within the body looked very much like the well-known clusters of Actinomyces. (See fig. 276 on Pl. XXII.) On the artificial substrate, however, only normal micrococci grew, though in the clusters short chains were seen, as were also obtained in cultures by *Babes* (1908).

Several other little known species, viz., *M. coronatus Flügge*, *M. coralloides Zimmermann*, *M. viticulosus Katz*, *M. polypus Mig.*, *M. nubilus Fontin*, and *M. vesicae Heim* (see *Lehmann* and *Neumann*, 1912, p. 234–235) are interesting on account of their tendency to form branches around the edge of their colonies and along their stab cultures in gelatin. The inclination to assume rod-like forms seems also to be not uncommon in these cases. *M. viticulosus* reminded *Lehmann* and *Neumann* (1912) somewhat of their *Bacterium vulgare* (Hauser's Proteus).

Meningococci and gonococci are also by no means the simple constant cocci, which they are often supposed to be. The meningococci are especially inclined to exhibit a great variability in their cell form, as well as in their stainability. The occurrence of very small up to very large cells has been declared by *Kutscher* (1907) to be characteristic for this species. Small cocci were seen by *Lehmann* and *Neumann* (1912, p. 223) attached like buds to the large, deeply staining "giant" forms. That the positive or negative reaction with the Gram method can not be used to distinguish two different species (the *Diplococcus intracellularis meningitidis Weichselbaum* and the *Meningococcus intracellularis Jaeger*) is proven by the investigations of *Köhlisch* (1915) and of *Hort*, *Lakin* and *Benians* (1915). According to *Köhlisch*, not only the Gram staining, but also the form of the colonies and the behavior in the agglutination test, may vary greatly. *Hort* and his collaborators called the attention to the important fact that the smallest granular forms, produced by the meningococcus, are able to pass the Berkefeld filter. On "nasgar" plates minute colonies were grown from the filtrate, and in one well isolated colony the following cell forms were found: (*a*) Gram-negative diplococci (Weichselbaum's cocci), (*b*) small Gram-negative bacilli, (*c*) Gram-positive and Gram-negative cocci (Jaeger's cocci), (*d*) Gram-negative rods ("biscuit bacilli") with mostly Gram-negative, sometimes Gram-positive granules, (*e*) Gram-positive bacilli of unequal size. The apparent multiple spore-formation in, and the budding of the "giant" cells, was accepted later by *Hort* (1917 *b*) to be sufficient reason to remove this organism entirely from the bacteria and to place it among the Hemiascomycetes. As was mentioned on page 22, and will be more fully discussed in Chapter II, both processes are quite common with all bacteria.

H. Herzog (1913) has published another highly interesting paper upon similar observations made with *Neisser's* Gonococcus. Analogous changes between large and small (filterable) forms take place, which will be more fully discussed in Chapter II, their reproductive character being quite apparent. A reproduction of his figure 6, shown as figure 2 on Plate A, throws an interesting light on the relations existing between giant coccus-, dumb-bell-, and micro-forms, which *Herzog* also observed with meningococci.

In the genus Streptococcus irregular rod-, club-, and dumb-bell-shaped forms are also by no means rare. *Rindfleisch* (1872) probably was the first to observe directly under the microscope the breaking up of rods into globular forms and the melting together of streptococci to rods. *Billroth* (1874) discovered, by direct observation, that the lactic-acid streptococci are able to produce buds and clubbed rods. He distinguished the streptococci from the micrococci generally by their being inclosed in a cylindrical sheath, which was sometimes seen to be partially emptied. *Rosenbach* (1884) pointed out that size and staining quality of pathogenic streptococci may vary widely, even within the same chain. *Maddox* (1886) found clublike forms of *Streptococcus lactis* frequently in cultures one month old. An organism described by *Cornil* and *Babes* (1890, Vol. I, p. 506) as causative agent of an "endocardite ulcéreuse" seems to have been a rod-forming Streptococcus:

> Bâtonnets de 1μ d'épaisseur, de 2 à 3 ou 4μ de longueur, elles se disposent parfois en chaînettes; les bâtonnets se changent en diplococci ou en microcoques plus ou moins arrondis . . . Parmi ces chaînettes on trouve aussi des grains ronds colorés de la même façon, plus gros, de 1μ, 5 de diamètre.

Pansini (1890) recorded with various streptococci (his Nos. 4 and 5) large oval and rod-like "involution" forms. Two years later, however, in *Kruse* and *Pansini's* important paper upon the relationship existing between pneumococci and pyogenic streptococci (1892, p. 283) it is said concerning their bacillary forms:

> Involutionsformen möchten wir dieselben nicht nennen, im Gegenteil schienen sie in diesem Falle einem Excess im Wachstum ihren Ursprung zu verdanken, denn die Culturen gediehen viel besser als anfänglich.

All intermediate stages were seen, rods showing beginning segmentation, and also large yeastlike cells. The fact, clearly brought out for the first time in this paper, that pneumococci, as well as other pathogenic and nonpathogenic streptococci, can not be separated as true species, but must be looked upon as more or less stable varieties, occasionally passing over into each other, has since then found ample confirmation by publications of *Lemoine* (1896), *Lehmann* and *Neumann* (1912), *Baerthlein* (1912), *Rosenow* (1914), *Heinemann* (1915), and others.

Arloing and *Chantre* (1894) noticed that the rod forms, whose greater vitality *Kruse* and *Pansini* had demonstrated culturally, were also more virulent in the animal test; the French authors also observed the regressive metamorphosis from the rods to the streptococci, and they concluded therefore:

> Il est probable que certains bacilles pyogènes ne sont que des streptocoques modifiés . . . Quand on trouvera des bacilles associés au streptocoque pyogène, il sera prudent de ne pas conclure nécessairement à une association microbienne.

The formation of clubs, branches, rods, large and small ovals, rhomboid bodies, apical growth, etc., with streptococci has been fully demonstrated by *Babes* (1895), who draws from his observations the following conclusion (p. 418):

> Ich stehe nicht an, eine nahe Verwandtschaft besonders jener kurzen Streptokokken, welche häufig Kolben bilden, mit den Diphtheriebacillen und ähnlichen Bakterien zuzugeben.

His figure 2 contains so many interesting details, which undoubtedly will gain in importance, when studied more closely in further investigations, that a reproduction of it is given as figure 3 on Plate B.

That contrary to a widespread assumption the streptococci do not only divide transversely, but also longitudinally within the chain, was also discussed by *Babes* and indicated in his drawings. The same fact and its connection with the formation of branches was further emphasized by *Crookshank* (1896, p. 179), who also dwelled upon the variable size and form of the cells, especially of those at the end of the chain. Evidently not being acquainted with *Billroth's* early findings, he continues:

> Another character which is very striking, may be seen when the individuals in a chain have become separated; an unstained or faintly stained membrane may be found bridging across the interval.

Such sheathed streptococci are also visible in *Babes'* sketches. They too furnish an interesting counterpart to similar sheathed granular forms produced by the Mycobacteria.

The *Streptococcus aggregatus*, isolated by Seitz (1896) from the mouth, was found to possess a wide pleomorphism of cells and of colonies. The latter were either small, looking like dewdrops or large, whitish, similar to the colonies of *B. pneumoniae*, or wrinkled and folded, like those of *B. mesentericus*. The size of the cells varied greatly. Regular "nests" were not rare, which contained all kinds of cocci, from the very smallest up to large "giant" forms, sometimes united in tetrades. Branching also was noticed. The globular forms changed into egg, onion, spindle, and lentil shapes, as well as into distinct short and long rod forms. All these various cells were sometimes present within the same chain. They were only partially Gram-positive. With this Streptococcus a diphtheroid organism was found in the mouth, whose cells and colonies remarkably resembled those of the Streptococcus.

A *Leuconostoc Lagerheimi* is, according to *Ludwig* (1896), dimorphous like *Leuconostoc* (Streptococcus) *mesenterioides*, viz., within the slime appearing as a regular Streptococcus, but when liberated, a motile short rod. *Beijerinck* (1898, p. 211), however, thinks that "*Leuconostoc Lagerheimi*" belongs actually to *B. xylinum Brown*.

The so-called *Micrococcus Sornthalii* of *Adametz* (1895), on the other hand, shows all marks of a true Streptococcus. On solid subtrates after some time large yeastlike cells became visible, which stained much better than the "normal" cocci.

Stolz (1898) found the large cells of pneumococci and pyogenic streptococci most frequently on serum agar. Rodlike forms, as well as clubs with short stems, singly or in short chains, were also present. Small cells and clubs showed often distinctly longitudinal division which led to branching, as was described before by *Babes* and by *Crookshank*. *Vincent* (1902) saw in pleuritic

exudate numerous bifurcate chains of streptococci, which continued growing in this manner when kept in a mixture of broth and human serum. Secondary branches were also formed, which, however, were very fragile like the others.

The slime-producing Streptoccoccus, which *Hlava* met in scarlatina, and for which the name *Leuconostoc hominis* was proposed by him, makes another excellent example of the relations connecting the streptococci and the diphtheria group. Some of *Hlava's* drawings, reproduced as figure 4 on Plate B, represent clearly all forms enumerated in the papers mentioned before. The transverse budding and branching, as well as the diphtheroid and yeastlike forms, are of special interest.

Thiercelin's Enterococcus is another example of a more thoroughly studied Streptococcus strain which exhibited all the various cell forms, characteristic of this group. In his first paper (1899) *Thiercelin* enumerates: Streptococci of very variable size, ovals with or without capsules, tetrades, staphylococci, short and long bacilli, and very large oval elements. He says:

> Ce microbe est doué d'un polymorphisme des plus remarquables et dans les cultures et dans l'organisme.

In his second paper (1903) the author reports that the very different forms abundantly present in old cultures continued to grow as such after being transferred to fresh substrates. On agar and in serum long threads, sometimes filled with granules, were also found. *Thiercelin* comes to the conclusion that the coccoid forms represent the young form of a bacillus:

> "L'entérocoque est la forme jeune d'une bactérie (entérobacille ou entérobactérie) . . . . La forme d'involution semble être un effort fait par le microbe vers cette forme bactérie."

Michaelis (1902) discovered large accumulations of clubbed forms of streptococci in pleuritic exudate. Because he was unable to obtain any development from them on his substrates, he feels sure that they are "degenerate" and the beginning of "bacteriolysis."

In a diphtheria test *Ohlmacher* (1902) encountered a streptococcus of such peculiar behavior that a doubtful diagnosis concerning the diphtheritic or nondiphtheritic nature of the case resulted. In broth typical streptococci appeared. On Loeffler's serum, however, very polymorphous rods with clubs or swollen centers were seen, together with other forms, which looked very much like diphtheria bacilli. The author agrees with *Babes* that such growth of streptococci may cause mistakes in the diagnosis of diphtheria.

The pronounced rod form occasionally assumed by *Streptococcus lactis* was the cause that this Streptococcus as *Bacterium lactis acidi Leichmann*, or *Bacterium Guentheri Lehmann et Neumann*, has been wrongly placed in another genus, though its close relationship especially to Pneumococcus has been pointed out already by *Leichmann* (1900, p. 324), and then more fully by *Kruse* (1903) and by *Löhnis* (1907–1911). Its changes in morphology have been also discussed by *Düggeli* (1905) and by *A. Wolff* (1908), who found out that the presence *of B. putrificus* greatly enhanced the tendency of the lactic-acid streptococci to pass over into spindle-, dumb-bell-shaped, and otherwise diphtheroid forms.

The Streptococcus isolated by *Lorenz* (1909) from horses afflicted with "Brustseuche' gave also small and large coccoid cells, some of them growing very similar to *Staphylococcus pyogenes aureus*, fine rods resembling *B. erysipelatos suum*, and branched diphtheroid and Actinomyces-like forms. The appearance of the last-named type of growth was especially conspicuous in the presence of an Aspergillus, and it was most frequently noticed on the surface of solid substrates, while in their depth, as well as in liquid media, the typical streptococci persisted. The changes in morphology were accompanied by equally marked alterations in virulence.

Taddei (1909) tried *Streptococcus pyogenes*, *choreae*, and *erysipelatos* on different substrates (broth diluted with water, or broth mixed with 0.25–1 per cent tartaric acid or lithium chloride) and found that all his strains, though rather stable on ordinary broth, developed on the changed media to rods, very small and very large ovals (up to 6–7μ). These altered forms remained constant, except when brought back into ordinary broth. The morphological changes were accompanied by a speedy loss of virulence. That essentially the same effect was secured by diluting the broth as by adding the substances named is of special interest.

In sugar media, used by *Broadhurst* (1915) in experiments upon the fermentative reactions of streptococci, also often considerable morphological changes became apparent. Rod-like, clubbed, pear-shaped, and obtusely diamond-shaped cells, as well as longitudinal dividing, were observed.

Mallory and *Medlar* (1916) say of their new *B. scarlatinae* that it approaches more nearly the strepto-pneumococcus group than the diphtheria group. It varies from coccus to long bacillary forms, grows best anaerobically, and is gram-positive. Its etiological significance remains to be studied.

Quite recently *Kraskowska* and *Nitsch* (1918) published some very good illustrations and a fairly complete description of the pleomorphism of streptococci, isolated from sick and from healthy persons. Their assumption that no such observations had been made before is, however, far from being correct.

The pleomorphous Streptococcus, which *Rosenow, Towne* and *Wheeler* (1916), *Nuzum* and *Herzog* (1916), *Rosenow* and *Towne* (1917), as well as *Mathers* (1917), consider to be the causative agent of poliomyelitis, a view which is not shared by *Amoss* (1917), *Bull* (1917), and others, shows once more the morphological changes characteristic to the streptococcus group. In this case the attention naturally was centered upon the production of minute, filterable coccoid forms, which, however, are by no means absent in the cultures of other streptococci. In this respect, too, the observations of the earlier investigators are in complete agreement with those of the authors named. Some of their photographs are reproduced as figures 9 and 10 on Plate I. For comparison one of our photographs of *Streptococcus lactis* (*Löhnis* and *Smith*, 1916 *b*) is added as figure 11, showing analogous differences in form and size. The picture of *Streptococcus tyrogenus*, reproduced as figure 12 on Plate I, was published by *Migula* (1900, Vol. II, Pl. I, fig. 2) as an illustration to his statement that the cells of this species are 2μ in diameter. The photograph, however, exhibits clearly large and very small forms, budding ovals and other details which were not mentioned by the author. The *Streptococcus equi*, reproduced as figure 13 on Plate II from another photograph of *Migula* (l. c., Pl. II, fig. 5) makes a very interesting counterpart to *Rosenow's* poliomyelitis picture.

It is evident that these observations will lead to discoveries of still more fundamental importance, especially when connected with those of *Herzog* and *Hort*, mentioned above. As the true character of these minute, filterable forms, however, seems to be more that of reproductive organs than of regular vegetative cells, the full discussion of their part in the life cycles of streptococci, micrococci, as well as of all other kinds of bacteria, will better be taken up from a general standpoint in Chapter II.

That the old form genus Sarcina is a rather hetereogeneous mixture of more or less similar cell forms, belonging to the life cycles of other organisms which are only partially related to each other, has been indicated above. Some sarcinae are obviously a special type of growth of various micrococci, as has been emphasized by *Lehmann* and *Neumann* (1912, p. 198) and others. The differences in the size of the cells are usually still more conspicuous than with micro- and streptococci, so that these authors explicitly state (l. c., p. 199):

> Angaben über Zellgrösse haben wir bei den Sarcinen nicht gemacht, weil wir hier besonders unregelmässige Resultate fanden. Es macht den Eindruck, als ob die Zellen oft gewaltig wüchsen und dann rasch hintereinander in acht Teile zerfielen.

Two copies taken from our second preliminary paper (1916 *b*) and reproduced as figures 14 and 15 on Plate II, may illustrate these differences in the cell form of *Sarcina flava*, when grown on beef agar 1 day and 3 months, respectively. Two others, figures 16 and 17 on the same plate, show the same organism after 6 days' growth in ammonium-citrate-glycerine solution. The breaking up of the larger forms into packages of small cells is fairly well discernible. The irregular outlines and the very dark staining of the large cells of fig. 16 are caused by their being newly formed from the symplasm, which process will be discussed in Chapter III.

Other sarcinae, however, will probably turn out, when studied more thoroughly, to be a special type of growth of various bacilli. *Beijerinck* (1901 *a*, p. 43, footnote) has already pointed out that *Miquel's* Urosarcina is no sarcina at all, but a bacillus, and a glance at the

drawing of *Urosarcina Hansenii Miq.*, reproduced as figure 6 on Plate C from *Miquel* and *Cambier's* Traité (1902, p. 628, fig. 172), confirms this standpoint. The Dutch author himself isolated some strains from soil which are said to represent intermediate forms connecting Sarcina and Bacillus Megaterium (l. c., p. 53, footnote). *Planosarcina ureae Beij.*, differing already from most other sarcinae by their ability to form endospores, is also distinctly inclined to produce small as well as large rods (*Löhnis* and *Smith*, 1916 *a*), though *Ellis* (1902) was unable to get a single rodlike cell with this or with any other sarcina.

As fig. 18 on Pl. II a photograph made by *Matzuschita* (1900, original fig. 6) is reproduced, showing the growth produced on salted substrates by a so-called *Bact. bruneum*, i. e. a brown variety of *B. fluorescens*. These cells have the typical appearance of regenerative bodies, yet they can be easily mistaken for sarcinae. A close study of *Sarcina mobilis Maurea*, the only organism within this group which is able to produce fluoresceine, might be of interest in this connection. *Lehmann* and *Neumann* (1912, p. 206) obtained the typical growth of *Sarcina tetragena* from an old culture of *Duclaux's Actinobacter polymorphus*. Contamination, of course, is also in this case not absolutely excluded, though not very probable. At least, there are too many parallels in the biological characters of *Sarcina tetragena* and of the *B. pneumoniae* group, to which Duclaux's Actinobacter belongs, to discard this finding lightly as contamination. *Ph. Eisenberg* (1914) noticed that also in mutation experiments *Sarcina tetragena* and *Bact. pneumoniae* resembled each other closely.

Figures 19–21 on Plate II are copies of some pictures of *Azotobacter vitreum*, published in 1914 as figures 22–24 in a paper by *Löhnis* and *Hanzawa*. This Azotobacter has a very firmly fixed tendency to show all morphological characters of a Sarcina. Yet it is no longer doubtful to me that this Azotobacter, like all others, is a type of growth of a spore-forming bacillus. But it was for the first time, after this strain had been under cultivation and observation for fully 10 years, that at least some large rods were produced and some inclination to form endospores became evident.

Billet (1890, p. 213) made the statement that all bacteria may appear as sarcinae by dividing themselves in three directions while in their "état zoogléique." This statement, however, is not sufficiently supported by facts. That, indeed, large packages of globular regenerative bodies may develop from the symplasm of every kind of bacteria, will be shown in Chapter III. But these irregular clumps bear, as a rule, only a slight resemblance to the typical sarcina forms, and it seems not to be a general rule that such "pseudo-sarcinae" are produced, as with *B. fluorescens* and *azotobacter*.

Sarcinastrum urosporae Lagerheim is another example of a bacillus with coccoid reproductive organs, which occur in packets like Sarcina. The rods, according to *Lagerheim* (1900) divide transversely and longitudinally, thus forming small cocci, which first increase in size and then germinate again to rods. Similar processes have been seen with other bacilli, e. g. with *Bact. Fraenkelii Hashimoto*, with *Matzuschita's* "proteusartigem Luftbacillus" and with *Bac. amylobacter* by *Bredemann*, to which we will have to refer on the following pages.

(b) NONSPORE-FORMING RODS.

Among the nonspore-forming rods the different *Proteus* varieties have been the first good examples of a distinct pleomorphism, morphologically as well as physiologically. It is true that *Hauser* (1885) at first made some concessions to the monomorphistic doctrine by creating three different species (*Pr. vulgaris*, *mirabilis*, and *Zenkeri*); few years later, however, he admitted that the differences existing between them were only sufficient to classify them as "physiological varieties" of one species. The typical forms, according to his description, are small cocci and short rods (0.4–0.6 × 0.9–1.2 μ). But there were also present in young cultures large rods and threads (1 × 7.5–37.5 μ), large round cells (of 1.6 μ diameter), well developed spirals (with 2–4 turns), long twisted "spirulines," and large pear and club shaped so-called involution forms (3–7 μ), which, however, were actively motile, multiplied as such, and were replaced in old cultures by the "normal" small rods and cocci.

Proteus fluorescens, discovered by *Jaeger* (1892) as a causative agent in Weil's disease, shows otherwise all morphological and cultural characters of this group, but produces fluoresceine. *Kohlbrugge* (1901) met with an interesting symbiosis of a proteus-like rod and a vibrio in feces. Both grew better when united, and the vibrio simulated the rod in its different forms (cocci, short rods and waved threads) to such an extent that only single-cell cultures secured the final decision. The *Bacillus proteus denitrificans of Höflich* (1902) furnished always at first long thin threads with pointed ends (0.3–0.4 ×20–100 μ); they divided into long rods (5–10 μ) and spirals, these into short rods and vibrios, at last coccoid and yeastlike forms appeared. All short forms reproduced long threads after each transfer. On account of its having several polar flagella *Lehmann* and *Neumann* (1912, p. 428) are somewhat in doubt, whether it really represents a Proteus form. Possibly the same dimorphism in flagellation (polar and peritrichous) occurs here, as it does with *B. coli*.

The "proteusartige Luftbacillus," briefly described by *Matzuschita* (1902), deserves our special attention not only because of its inclination to longitudinal fission, but still more because the various "involution" forms, as shown in the reproduction of some of *Matzuschita's* drawings in figure 5 on Plate B, will prove to be of special interest, when viewed (in Chap. II) in the light derived from other observations on hitherto very little known reproductive processes in the life history of the bacteria.

Under the designation "*Bacterium pyogenes ramosum*," *Stefansky* (1902) added another so-called species to the Proteus group, which in the pus from an abscess of the skin showed exclusively the form of a coccus, while on the plate nothing but short rods became visible. They produced within 24 hours longer rods and threads with spindle- and club-shaped inflations, in broth large globules also, and Y-forms. On agar containing 5 per cent NaCl the highly pleomorphous picture, presented already by the other forms, became still more complicated by the presence of ring-shaped, spirilla and spirochaete-like forms, as well as of branched cells.

Bacterium Zopfii, described by *Kurth* (1883) two years before *Hauser* published his monograph on Proteus, is closely related to Proteus Zenkeri, as I have shown (1905 *a*, p. 720) by a comparative study of a number of varieties. *Kurth* was not able to obtain a multiplication of the cocci as such. They always reproduced rods, and were therefore considered by him to be resting forms. They originated by fragmentation of the rods. *Schedtler* (1887) confirmed these findings by direct continuous microscopic studies. He also saw branched spirals.

Whether *Bacterium merismopedioides* of *Zopf* (1883) belongs to this group can not be decided, as only insufficient data are available. Its breaking up into cocci, forming tetrades and sarcina-like arrangements, as shown in fig. 7 on Plate C, indicate, however, a morphological relationship to *Bact. Zopfii Kurth*, as well as to Matzuschita's protean bacillus from the air. *Zopf* saw motility of the "cocci", whereas those of *Bact. Zopfii* were found to be immotile.

The Lactobacilli furnish many more details, which do not fit the monomorphistic theory. Long slender rods are typical, but short rods and cocci are by no means rare, and branching can be observed so readily that some investigators not only discussed the relations connecting lactobacilli and actinomycetes, but directly transferred the lactobacilli into the last-named group. *C. Sternberg* (1898) is one of the few authors who claims to have seen motile lophotrichous rods of the Boas-Oppler bacillus. The same author also recorded clostridia, plectridia, and regular endospore-formation. (See Chap. II.) The two best-known lactobacilli from the intestinal tract, *Bacillus acidophilus Moro* (1900) and *B. bifidus Tissier* (1900), are both very much inclined to exhibit the characteristic branching. *Moro* found water cultures very useful for this purpose. So-called degeneration forms (ring, club-shaped forms, spirals and others) were frequent on agar after a few days. Some of *Tissier's* drawings, reproduced as figure 8 on Plate C, show many features to be found with *B. radicicola* and other members of the *B. pneumoniae* group. That there are connections linking the lactobacilli on the one side with these organisms, and on the other side with the streptococci, has been discussed in my paper on the lactic acid bacteria (1907). *Tissier* (l. c., p. 91) declares the "formes vésiculeuses" to be signs of degeneration. But it seems more probable that they represent a special intermediary step in the life cycle of this organism, as well as of others, e. g. with *B. pneumoniae* (see *Toennies-*

sen's findings below). Branched forms are, according to *Tissier*, frequent in feces, on good substrates after they are somewhat exhausted or have turned acid, and often under the influence of symbiosis with other bacteria. Just as with *B. radiciola*, the three ends of a Y form are not infrequently the only parts which take the stain, and which are able to give further development.

Another strain of the Acidophilus type, isolated by *Cahn* (1901), was given the special name "*B. aërobicus ramificatus*" on account of its abundant branching. *Rodella* (1901) found the pleomorphism of this group so bewildering that he was unable to decide whether the different strains studied by him should be given species or only varietal character. When treated with the Gram method, the rods behaved very much like diphtheria bacilli, showing gram-positive and gram-negative parts. Continued investigations led to the conclusion (*Rodella*, 1908) that practically all lactobacilli from the stomach (Boas-Oppler bacillus, *B. gastrophilus, acidophilus* and *bifidus*) are merely representatives of one single species. *Blühdorn* (1913), on the other hand, vigorously maintained that there be no similarity whatever between the two last-named bacilli; they are said to be entirely different, morphologically as well as physiologically. Undoubtedly both extreme views are incorrect. There is neither a complete identity, nor an absolute nonidentity. All lactobacilli together form a natural group, and not before their full life history is known, we will be able to say, whether it is made up of different species or only of a chain of varieties. At present, the latter view seems to be more probable. What surprises are still in store for more thorough investigations is indicated by the discovery made by *Noguchi* (1910), that *Bac. bifidus* is "an anaerobic phase of life of an aerobic sporogenous organism . . . closely resembling *Bac. mesentericus fuscus*." *Noguchi* was able to complete experimentally the transformations both ways. *Sandberg* (1904) who also saw motility, made some important observations upon the correlations existing between the different variable types of colonies and the form of rods, produced by the "long bacilli" from the stomach.

The lactobacilli in milk, cheese, and other fermented food, exhibit the same instability of appearance when growing under different conditions. Besides the "normal" slender rods, long threads with inflations, as well as chains looking very much like streptococci, are equally frequent. *Henneberg* (1901), *Holliger* (1902), *Freudenreich* and *Thöni* (1905) and many others have furnished valuable information upon these organisms, which was collected some years ago in my papers on lactic acid bacteria (1907, 1911). From our present standpoint the following publications are of special interest: *Düggeli* (1905) and *Weigmann, Gruber* and *Huss* (1907) on the organisms in the Armenian sour milk (matzoon); *Rubinsky* (1910) upon the koumiss bacterium; *Chatterjee* (1910) on the lactobacillus (mistaken by this author for a Streptothrix) in the fermented milk of British India, called dadhi; *Heinemann* and *Hefferan* (1909) and *Koegel* (1914) on the bacillus from Bulgarian sour milk (yaourt), usually, though wrongly, termed *B. bulgaricus*. Undoubtedly the polymorphism of this group surpasses by far that of Proteus, and is perhaps even more pronounced than that of the plague bacillus and of the diphtheria group. Starting from the short, coccoid and club-shaped cells, practically all intermediate forms may become visible up to the very thin threads with pointed ends, sometimes only 0.2–0.3 μ thick, not infrequently waved and coiled, and often branched. The plates attached to the papers of *Weigmann* et al. and of *Rubinsky* may be consulted for good illustrations.

Among the organisms of this group *Bact. acidi propionici b* of *Freudenreich* and *Jensen* (1906) is perhaps the best example thus far known, exhibiting marks of relationship between the lactobacilli and the diphtheria group. At room temperature appearing as a small short rod ($\frac{1}{2} \times 1\mu$), it becomes a long rod at 37° C., forming clubs which stain like the barred type of the diphtheria group. Granules showing the *Neisser* reaction may be found occasionally with all lactobacilli. The "Körnchenbacillen" of some German authors can not be accepted as a special type.

That at least some of the old, poorly described Leptothrix forms are to be classified with the lactobacilli can hardly be doubted. In some of the early publications of *W. Miller* (1882–1889) the pleomorphism of this group has been already fairly well indicated, though, of course, no definite information can be gained from these necessarily very incomplete investigations

Bac. funduliformis Hallé (1898, pp. 28–31) and some other anaerobic nonspore-forming bacilli seem also to be naturally related to the lactobacilli, especially to those displaying a distinctly anaerobic character. On the other hand, they are also related to anaerobic spore-forming bacilli. The same, however, holds true for the lactobacilli, as will be more fully discussed in Chapter II. *Hallé's* vaginal bacillus grows in the pus as a slightly curved thin immotile rod, but in the cultures a conspicuous pleomorphism was noticeable, as illustrated in figure 9 Plate C (from original fig. 3). Large rods and threads, with inflations, branches, buds, clubs, balls, etc., were formed; in the animal tests oedema and gangrene were caused.

An anaerobic bacterium, found by *Ghon* and *Sachs* (1905) to be connected with peritonitis, and either identical or closely related to *B. funduliformis*, gave also prominently small immotile rods, slightly longer and thicker than the influenza bacillus, accompanied by cocci, threads and inflated forms, when taken from the exudate. In the cultures the pleomorphism became more enhanced by the presence of thick waved threads, club- and pear-shaped cells, ovals, yeastlike, and spindle forms, all of which were Gram-negative, and whose development was stimulated by adding 1 to 2 per cent glucose to the substrate. *Kisskalt* (1906) studied a similar organism, isolated from an abscess, and emphasized its relationship to the Streptotrices. Three other small Gram-negative anaerobic rods, isolated from meningitis by *Ghon*, *Mucha* and *Müller* (1906) are also to be included in this group. They are either identical or closely related with each other. Their appearance after 4 days growth at 37° C. is illustrated in figure 10 on Plate C (reproduced from original figs. 6, 9 and 20).

Several other organisms found in cases of typhus exanthematicus, whose etiologic significance is still more or less questionable, are also to be mentioned here. The immotile diplobacillus of *M. Rabinowitsch* (1909), showing bipolar staining, and the organism described by *P. Th. Müller* (1913), are apparently either closely related or even identical. In the blood they appear as cocci, diplococci, and short rods; but in the pericardial liquid large globules, ovals, yeast like and big dumb-bell or club-shaped cells occur. The figures reproduced as Nos. 22–24 on Plate II (from original figs. 2, 5, and 1, respectively) show coccoid forms from gelatin, 2 days old, rods from glycerine agar, 2 days old, and so-called degeneration forms from serum broth, 8 days old. The latter especially indicate relations to the mycobacteria. In their paper upon the diphtheria group *Trautmann* and *Gaethgens* (1913) have published a photograph (fig. 8, p. 72) demonstrating exactly the same type of clubs, cocci, and short rods. Gram staining was either positive or negative with *Müller's* organism. *Plotz, Olitzky* and *Baehr* (1915) also isolated a pleomorphous, Gram-positive, small bacillus from typhus cases, which grew either as a coccus, or as a short straight or curved rod, and which was very much inclined to produce, in young cultures, so-called involution and degeneration forms. The authors use these expressions, though they found that these special forms can be made constant by frequent transfers, which fact undoubtedly does not fit their assumed "degenerate" character. The filterability of the typhus virus is not admitted by these authors. However, here as in other cases the observations of *Hort* (1915) seem to be an important step toward the solution of the problem. It is very probable that his small Gram-positive or Gram-negative filterable organism is nothing else than the gonidial stage of the pleomorphous rod found by the other authors. In Chapter II this point will be more fully discussed.

B. erysipelatos suum, *B. murisepticum*, and *B. erysipeloides*, considered by *Rosenbach* to be different, while other authors accept them as identical (see *Lehmann* and *Neumann*, 1912, p. 430), furnish another prominent example against the monomorphistic theory. First described by *Rosenbach* (1884) as micrococcus, soon after, however, declared by him (1887) to be neither a micrococcus, nor a bacterium, nor a bacillus, but an organism of peculiar systematic standing, perhaps related to Cladothrix, it has been more recently studied anew by the same author (1909), whereupon it was made the type of a new genus Erysipelothrix. Four of the photographs accompanying the last-named paper have been reproduced as figures 26–29 on Plate III. Figure 26 (original fig. XIII, 5) represents *B. erysipeloides* from blood serum, 7 days old. Figure 27 (original fig. XII, 5) shows the same organism from broth, only 9 hours

old; branching, terminal swelling, as well as budding, are clearly visible. Figure 28 (original fig. XIII, 3) demonstrates a spiral form of *B. murisepticum* in gelatin, and figure 29 (original fig. XII, 3) a thin mycelial growth of *B. erysipeloides* from a 6-weeks-old gelatin culture, resembling very much a similar development of lactobacilli (shown e. g. in *Rubinsky's* koumiss paper). Another picture of *B. erysipelatos suum*, taken from the "Atlas" of *Itzerott* and *Niemann* (1895, fig. 40), has been added for comparison as figure 25 on Plate III. That also in this case very different cell forms, as well as budding, are easily discernible, demonstrates sufficiently how difficult it is to get "legitimate" monomorphous material; for it may be safely assumed that the authors have selected a field as uniform as they could find. As early as in 1889 *Karlinski* introduced a "new pathogenic schizomyces" under the name *Bac. murisepticus pleomorphus* into the literature, which already clearly exhibits most of the marks mentioned by *Rosenbach* 20 years later as characterizing his Erysipelothrix. *Karlinski* emphasized the protean nature of his bacillus. The short rod was considered to be typical, but "nearly all forms became visible, from small, globular and oval cells up to slender spirals," and in old cultures "terminal swellings appeared, often five times as thick as the rods and threads," which the author felt "compelled" to classify as "involution" forms. That under special conditions, as mentioned on p. 40, *Lorenz* (1892) obtained an actinomyces-like growth of *B. erysipelatos suum* is quite in line with these other findings. And it is very probable, too, that the "Streptothrix" growth which *Kitt* (1897) found in his "Rotlauf" cultures, when kept in serum broth, was not a contamination, as he later (1898) assumed, but really the analogous type of growth, as in the other cases. (See also p. 20.)

B. septicaemiae haemorrhagicae has been represented in the "Atlas" of *Itzerott* and *Niemann* (1895, fig. 36, "Hühnercholera") by the photograph reproduced as fig. 30 on Plate III. It is certainly not easy to understand how the authors actually photographed unknowingly something quite different from the typical bipolar rods, which they undoubtedly intended to show. Evidently they were so well trained to see only "bipolar rods" that all the single globular bodies, their budding (in the center of the picture), and their Staphylococcus-like arrangement were passed unnoticed. It is a good example of well-developed regenerative bodies, photographed but not seen. A comparison with figure 18 on Plate II (regenerative bodies of a Fluorescens variety) might be recommended. *Rosenfeld* (1901) noticed that the addition of salt stimulated the formation of ring-shaped, globular, thread-like, and branched cells in the septicaemia group as in others. *G. Phisalix* (1902) found the mycelium-like growth of Pasteurella in the body, while in the cultures the cocco-bacillary form reappeared; the virulence was the same in both cases. *Bang's* abortus bacillus has been classed by *Nowak* (1908) as a pleomorphous member of the septicaemia group, showing coccoid, branched, and various other forms, but it seems more correct to place this organism among the mycobacteria. *Klepzoff* (1912) succeeded in getting acid-fast growth from septicaemia organisms in the course of experiments, which led to the discovery of relations existing between *B. tuberculosis* and *Pasteurella* groups.

B. pseudotuberculosis rodentium has been studied by *Galli-Valerio* (1903) and *Zlatogoroff* (1904) in regard to its pleomorphism and its relation to *B. pestis*. Very similar small and large as well as branched cells were found to be frequent with both organisms. A "new species" *Bacterium pseudopestis murium* described more recently by *Galli-Valerio* (1913) may be also accepted as an aberrant strain of *B. pseudotuberculosis rodentium*. Its plague-like pleomorphism deserves full attention with respect to the plague diagnosis.

The wide variations in the microscopical appearance of *B. pestis* have been made the object of numerous studies; those of *E. Klein* (1897) upon the correlations existing between cell forms and colony types of *B. pestis* apparently being the first of its kind. A very detailed report upon plague morphology has been furnished by *Albrecht* and *Ghon* (1900). The reproductions of a few of their drawings, given in figure 11 on Plate D, present a good illustration of the very wide pleomorphism characteristic for this organism.

Coccoid forms are considered to be the initial type of growth. They pass over into the short rods showing bipolar staining, and therefore occasionally looking like diplo- and streptococci. Later the cells increase in size, some swelling up to yeast-like, pear-, club-, or spindle-

shaped appearance, others stretching out into threads, which sometimes show branching or a conspicuous swelling in the center. All these forms are present in the body, as well as in the cultures. That the large cells are no "involution" forms, is not only proved by their vitality, but still more by the fact that in several months old cultures the coccoid forms exclusively are to be found. Budding and branching is frequent after not more than 48 hours on glycerin agar. *Skschivan* (1900) saw it in only 1-day-old growth, and he is therefore inclined to place the plague bacillus among the actinomycetes, next to *B. mallei*. *Dieudonné* (1903) calls again all forms surpassing the "legitimate" coccoid or short-rod type, "involution or degeneration forms," though they are, according to his own statement, fully virulent, present already in the bubo after a short time, and most frequently obtainable in fresh isolations from the animal. Figures 31–33 on Plate III are reproductions from the textbook of *Muir* and *Ritchie* (1903). Figure 31 (original fig. 148) shows the so-called normal coccoid and rod-like cells from a young agar culture, figure 32 (original fig. 150) the "involution" forms from 4 per cent salt agar, and figure 33 (original fig. 147) the microscopical appearance of the organisms as taken from the tissue. There is unquestionably much likeness between figures 33 and 32, but hardly any between 33 and 31.

The difficulties occasionally arising from the microscopical similarity of *B. pestis* and *B. pseudotuberculosis rodentium* have been discussed by *Galli-Valerio* (1903) and by *Zlatogoroff* (1904) in papers referred to above. The conditions favoring one or the other type of growth have been the object of special studies by *Cacace* (1903). Long and sometimes branched Streptothrix-like threads were e. g. easily obtained in broth, containing 0.01–0.05 per cent potassium chromate, while the addition of 0.5–1.5 per cent carbolic acid to the broth stimulated the growth of cocci, which equally predominated on gypsum plates saturated with broth. Abundant and uniform branching was secured by *Kodama* (1908) with 10 strains of *B. pestis* when these were cultivated on coagulated egg albumen. *Gotschlich* (1906) reported upon an avirulent plague "mutation" which grew in smooth, circular colonies, but reverted in two of three cases to the original type, after having been kept for two months in the icebox. *Rowland* (1912) was able to transform experimentally the plague bacillus into a strain showing all characters of *B. pseudotuberculosis rodentium*. In another paper he states that "probably no organism presents so marked a pleomorphism as the bacillus of plague," and he demonstrates this by a large collection of beautiful photographs, two of which are reproduced on Plate III: Figure 34 (original fig. 12, Pl. XIX) mycelial growth in immune serum, and figure 35 (original fig. 17, Pl. XXI) yeast-like cells from the seat of inoculation in the rat. The correlations existing between cell form, virulence, and appearance of the colonies have been studied anew by *Markl* (1914). Highly virulent, freshly isolated strains gave small thin colonies, while others, more or less reduced in virulence by prolonged cultivation on artificial substrates, produced large succulent colonies. The single cells, however, were larger and thicker in the virulent than in the saprophytic strains. An entirely avirulent pseudo-plague bacillus from the soil, which I described (1905 *b*) under the name *Bact. agreste*, exhibited a surprising similarity to the true plague bacillus, morphologically as well as physiologically, but differed from it by being, at least temporarily, actively motile.

The various cell forms of *B. influenzae* have been demonstrated by *Crookshank* (1896) in the drawing reproduced as figure 12 on Plate D (from original fig. 122). The filaments are composed of long and short rods, coccus forms of different size, and of irregular elements. According to *Grassberger* (1898) the latter are present especially in luxuriantly growing cultures. Thick wedge-, spindle- and club-shaped cells are produced. True branching also was observed and photographed. On horse serum all 40 strains tested developed uniformly very long threads, which occasionally showed one or more inflations. *D. J. Davis* (1907) found that also in this case the presence of 2–3 per cent sodium chloride in the substrate stimulated the tendency to pass over into irregular large forms, somewhat resembling the diphtheria organism. But these alterations were not thought by him to be characteristic.

A very remarkable polymorphism has been described by *Waelsch* (1905) for his *B. involutus*, which *Lehmann* and *Neumann* (1912, p. 274) place close to the Morax-Axenfeld conjunctivitis

bacillus, but which also shows signs of relationship to the *B. pneumoniae* group. Very different forms were already present in the colonies. After a few days' growth representatives of practically all of *Cohn's* form genera appeared in the field. Figure 13 *a* on Plate D is a reproduction of the original figure 4, showing the development on glycerin agar after three days. Figure 13 *b* (original fig. 6) gives the picture of a 5-days-old broth culture.

Among the species or varieties belonging to the group of *Friedländer's B. pneumoniae* the so-called *Proteus hominis capsulatus*, as described by *Bordoni-Uffreduzzi* (1888 *b*) represents a form which in regard to its pleomorphism comes very near to *B. involutus Waelsch*. Besides the cocci, rods, and threads, which are characteristic for the group, and large globules acting as reproductive organs, very different spindle-shaped, curved, and triangular forms became visible on potato, which might be easily mistaken for "degenerate" spirilla. Figure 14 on Plate D (a reproduction of original fig. 3 on Pl. VII) shows them, as well as some branching. As the author explicitly says, they are no "involution" forms, because they are formed when the development is at its height, and they are replaced by the simpler forms when the culture grows older.

The *B. mucosus* isolated by *Simoni* (1900) from ozaena is another interesting example of the pronounced pleomorphism of the *B. pneumoniae* group. In the body typical cocci predominated, while in the cultures, especially on solid substrates, the bacilli came to the foreground. At the same time, however, so many other forms were already visible in young cultures, that only by repeated experiments full certainty about the absence of contaminations could be secured.

The "new species," isolated by *Jehle* (1902) from sputa in different cases of pulmonar affections, possesses all marks of Friedländer's bacillus. Cocci pass over into short rods, these stretch out into long, thick, often curved threads, which eventually exhibit spindle-shaped or globular inflations. All these various forms are present in cultures not older than 2–3 days. *Sachs'* "Kapselbacillus" (1903) displayed practically the same pleomorphism.

B. Berestnewi of *Lepeschkin* (1904) should probably also find its place here, according to its origin (sputum from a pneumonia case) and its general morphological and cultural characters. It produced the typical round, white, soft colonies, but was avirulent. The change between cocci, rod-like, and thread forms followed the common lines, though the size of the cells was larger than usual, and there was a very pronounced tendency to produce branched rods and threads. This tendency could be increased and stabilized in single-cell cultures, and it was much more noticeable with young than with old material. My own investigations (1905 *a*, p. 587) revealed very clearly that all members of the *B. pneumoniae* group are easily induced to display their ability of forming branches (so-called bacteroids). *Péju* and *Rajat* (1906 *c* and *e*) found potassium iodide, as well as urea, especially useful for stimulating the characteristic changes in appearance; 1–2 drops KI favored the development of very large round cells (of 3 to 4 times the normal size), while 10 drops increased the formation of long threads.

Some very interesting work upon the transformation of the large encapsulated ovals, not infrequently seen with the Friedländer bacillus, into slender small coli-like rods, has been done by *Toenniessen* (1913–14), who accepted these changes as "mutations," though they evidently represent different stages in the life history of this organism. Six of his photographs (Nos. III–VIII) are reproduced as figures 37–42 on Plate IV. The irregular intermediate forms, in which the chromatine granule only takes the stain, deserve our special attention. They, too, indicate the relationship existing between *B. pneumoniae* and *radicicola*. Their exact place in the life cycle of members of this group will have to be discussed in Chapter III. The thin coli-like rods proved to be entirely avirulent, but they reverted to the original short virulent type, when transfers were made from 6–8 weeks old cultures. The *Coccobacillus foetidus ozaenae Perez*, recently studied by *H. C. Ward* (1917), furnishes another example of the pleomorphous nature of this group. Besides the well-known differences in shape and size of the cells, variations in the motility were observed. Some strains remained permanently immotile, while others gained motility, thereby indicating, also in this respect, their tendency to approach the Coli type. That in old cultures a dark brown pigment became noticeable, is not surprising in

view of the fact that the same behavior is often ascertainable with typical strains of *B. pneumoniae*.

Two highly pleomorphous organisms, both probably related to *B. coli*, have been isolated in a case of oedema by *Harris* (1893). One showed a brownish, the other a pink color; the former was pathogenic, the latter was not. Both of them produced at first cocci and diplococci, which later developed into paired stout rods (1×4–6μ), or thin long rods and threads (0.5×4–12μ), respectively. Sometimes the pink organism exhibited distinctly Leptothrix-like forms. Budding and branching are also shown in the photographs accompanying the paper, but there is no word about them to be found in the text. In a paper entitled "The Pleomorphism of the Common Colon Bacillus," *Haslam* (1898) discussed the influence of quality and quantity of nitrogenous food upon the length and the width of the cell form. *Adami*, *Abbott*, and *Nicholson* (1899) discovered in cirrhotic, and also in normal, livers of men and animals minute spherical or oval bodies, which could be easily mistaken for pigment granules in the liver cells, occurring singly or in pairs, sometimes in strings of three and four, which on artificial substrates produced small colonies quite different from those of *B. coli*. Yet successive transfers led back to the typical colony and cell form of *B. coli*. *M. E. Abbott* (1900) has published some more data upon these investigations, to which reference will be made in Chapter II. Cultivation of *B. coli* on salt agar furnished *Matzuschita* (1900) large monstrous inflated threads. Figure 36 on Plate III is a reproduction of his figure 14. Another Coli strain gave large globules. Both forms are, as will be shown in Chapter II, of the same physiological value. *W. Winkler* (1900) observed granulated spindle-shaped "swarming bodies" of *B. coli*, which are probably of the same rank as analogous forms discovered by *Matzuschita* as a type of growth of his protean bacillus from air (fig. 5 on Pl. B). *Ohlmacher* (1902) isolated from a colon bacillus septicaemia a highly pleomorphous coli strain which only after several transplantations ("rejuvenation") in broth assumed again the "typical" behavior. "All gradations from minute coccoid or diplococcoid to long coarse filamentous forms were observed." Other threads were quite thin and shadowy. Some contained a row of deeply staining inclusions. Others in young cultures made from heart's blood showed lateral buds and short true branches. Some of the rods and filaments had median swellings, others clubbed ends. According to *Prell* (1917) *B. coli* may live in a "rhabdocytic" and in a "coccocytic" phase, and other bacteria may grow in a similar manner.

Walker and *Murray* (1904) discovered that 0.2 per cent saturated alcoholic solution of methyl violet added to agar, broth or gelatin, caused typhoid and coli bacilli to grow in long undulated, sometimes very thick, threads, which showed true branching and segmented in old cultures into chains of cocci. The authors expressed the belief that these alterations indicate "an unexpected complexity in the life history of these microörganisms." Data to be given in Chapter II will prove the correctness of their assumption. *Péju* and *Rajat* (1906 *b* and *e*) obtained analogous results by adding potassium iodide or urea to their substrates; and these were confirmed by other tests with urea made by *Wilson* simultaneously (1907). *Revis* (1912 *a*) succeeded, by making use of malachite green, in changing one of three Coli strains to such an extent that it now was "neither physiologically, morphologically, nor culturally a colon bacillus." It produced slime and grew in long filaments or as very short rods. The same author also studied (1912 *b*) the coccoid forms of *B. coli* and came to the conclusion that relations seem to exist with Gram-negative micro- and streptococci, analogous to those connecting Gram-positive streptococci and Gram-positive rods producing lactic acid. *Lehmann* and *Neumann* (1912, p. 256, footnote) observed occasionally that a monotrichous Coli strain became peritrichous, and the opposite change was recorded for *B. alcaligenes faecalis*, which first was described to be peritrichous, later monotrichous (*Lehmann* and *Neumann*, 1912, p. 357). When *Pollak* (1913) cultivated this organism on Dieudonné's blood agar, he obtained cholera-like colonies, and the rods appeared like vibrios. On the other hand, several vibrios have been found to be inclined to assume coli-like growth, as will be discussed later. Special investigations upon the natural relationship which seems to exist in this direction, might lead to very interesting results.

Some pictures, shown by *Kellerman* and *Scales* (1916) as illustrating certain phases in the life cycle of *B. coli*, are reproduced as figures 43-45 on Plate IV. Figure 43 makes an interesting counterpart to the preceding pictures of *B. pneumoniae*. The clusters of large globules and the hyphae-like threads in figure 45 represent forms whose physiological significance will be discussed later. The small unstained thread containing four chromatine granules (in the lower left part of fig. 44), also deserves our attention. Similar pictures of *B. coli* published by *Hort* (1917 *a*) will find their place better in Chapter II (Pl. XIII, fig. 180), as they are especially suited for explanatory purposes. The same holds true in regard to other data upon the behavior of the typhoid and dysentery organisms, contained in the same paper, and also in regard to drawings of *Meirowsky* (1914 *b*) illustrating similar phases in the life history of *B. paratyphosus B.*

Matzuschita (1900) published a photograph of the typhoid bacillus grown on salt agar which is reproduced as figure 46 on Plate IV (from original fig. 16). It should be compared with figure 36 on Plate III, showing the development of *B. coli* under analogous conditions. Other examples of true branching are to be found in a photograph of *B. typhosus* published by *Itzerott* and *Niemann* (1895) in their "Atlas" (original fig. 18), reproduced as figure 47 on Plate IV. The material used in this case, was taken from an agar culture. *Gamaleia* (1900) studied the peculiar effect exerted by lithium salts. Large globules and branched forms became very frequent. That these and other alterations of the cell form are not merely passive, osmotic reactions, as was later assumed by *Loeb* (1902), has been already emphasized by *Gamaleia* (l. c., p. 211). *Casagrandi* (1901) found cultivation on gypsum plates very useful for developing the branched growth of *B. typhosus*. *Walker* and *Murray* (1904) attained the same result by adding 0.2 per cent alcoholic methyl violet solution to agar, gelatin or broth, while *Péju* and *Rajat* (1906 *a*) and *Rajat* and *Péju* (1906) were only able to induce the typhoid bacillus, when treated with potassium iodide, to produce long immotile threads showing oval, pear- or spindle-shaped inflations, but no branching. In old cultures fragmentation of the long forms into short rods and coccoid forms was frequently observed. Urea agar furnished *Wilson* (1907) analogous, filamentous, round, and swollen forms, and also true branching. As early as in 1893 *Almquist* had pointed out that *B. typhosus* not only multiplies by fission, but also by producing lateral round buds which grow up to new rods. Later (1904) he added, that also very thin needle-like rods may directly come out from the old rods. These, as well as his other findings concerning the reproduction of the bacteria will be considered more specifically in Chapters II and III. *Bernhardt's* (1915) studies "upon the variability of pathogenic bacteria" confirm the earlier findings of thick immotile threads being formed by *B. typhosus* in old cultures, which still later break up into normal motile short rods; in a few cases, however, motility was lost permanently.

That occasionally paratyphoid strains can assume all marks of the true typhoid organism, and vice versa, has been shown by *Köhlisch* (1918) and by *Baerthlein* (1918). The first named author also reported (1916) upon some interesting yellow variants of the typhoid-paratyphoid group.

Valuable results with dysentery bacilli were secured by *Hata* (1908) when he studied the so-called "degeneration" forms of *B. pestis, typhosus, dysenteriae, coli,* and *cholerae*, produced on agar containing various amounts of $CaCl_2$, $MgCl_2$, or NaCl. Dysentery organisms were the only ones which "degenerated" already on 1 per cent $CaCl_2$ agar, i. e., the thin cells became larger and longer, and with increased salt content they assumed giant spindle forms. Some strains furnished in addition large globules. True branching was frequent on NaCl agar. Disappearance and reappearance of motility in dysentery strains have been discussed in a paper by *Dunn* (1904). The experiments of *Péju* and *Rajat* (1906 *d* and *e*) with potassium iodide and urea gave results analogous to those mentioned before. Inflated threads and globules were produced, which later partially broke up into normal short rods. Data concerning the correlations existing between different cell forms and appearance of the colonies in the typhoid-dysentery group are to be found in *Baerthlein's* (1912) report on "mutation" among bacteria.

The acetic acid bacteria are demonstrating their close relationship to the pneumonia-colon group, as in other directions, so also by their inclination to form the same type of large globules

and inflated threads, which later reproduce the small "normal" forms. But it is very characteristic that in this special case the large forms, though put aside in all other cases without any adequate test as uninteresting "involution forms," have been generally accepted in the textbooks as some important peculiarity of the acetic acid bacteria, because in this case a well-known investigator, *E. Chr. Hansen* (1879), before the monomorphistic doctrine took possession of most of the bacteriological textbooks, has pointed out that they belong to the normal life cycle of these organisms. He also observed directly (1894) their formation and their segmentation into small rods in single-cell cultures of *B. aceti* and of *B. Pasteurianum*. Figure 15 on Plate E is a reproduction from his first paper (now fig. 77 on p. 458 in his "Gesammelte theoretische Abhandlungen," 1911). *Lafar*, on the other hand, was at least for some time of the opinion that the large forms should be considered to be "pathologic deformities," because he noticed that increased acidity stimulated their development. However, an acid substrate is the natural habitat of these organisms, and their development is at its height under such conditions. *Zeidler* (1896) described a motile acetic acid bacterium, also representing the characteristic threads and inflations. *Henneberg* (1897–1898) created numerous "new species," which all showed the same character. He emphasizes the diagnostic importance of their "hypertrophism" and pays special attention to those lateral buds which are produced by the acetic acid bacteria in the same manner as by the lactobacilli. They appear on beer after two days and at temperatures as low as 26–29° C. *Kruse* (1910, p. 1126) admits that the luxurious growth on natural substrates is made up by the large forms, while the poor growth on artificial media shows only small short rods; and yet he still calls the former "quaint involution forms." In a special study upon this group *Janke* (1916) introduces the new term "aberration" forms, though he accepts them at the same time as part of the "normal" life cycle of the acetic acid bacteria, which, therefore, if these authors were right, would be "normally aberrant" or "normally degenerate" while growing luxuriantly under natural conditions.

Some of the so-called photobacteria form another interesting branch of the *B. pneumoniae* group. Their characteristic pleomorphism has been well illustrated in a little known paper by *Barnard* (1899), as well as in the more often quoted publications of *Molisch* (1903–1904). *Reinelt* (1905) has added other details; cocci and rods were present in all his cultures. That sometimes branched forms appear, like those of *B. radiciola*, had been already mentioned by *Beijerinck* in 1889.

The pleomorphism of *B. radicicola*, especially its inclination to grow in branched or in radiate forms, was also well established from the beginning by the publications of *Beijerinck* (1888–1890) and of *Prazmowski* (1890). Unfortunately, the incorrect term "bacteroids" has been widely adopted for this type of growth, though there is not the least doubt that *Brunchorst* and *Frank* were wrong when they assumed that only cell products looking like bacteria, and not real bacteria, were present in the root nodules of the leguminous plants. The radiate growth was considered by *Beijerinck* as indicating relations to the Actinomycetes. *Peklo* (1910) has dwelled upon this point in a paper on "plant actinomycoses." Like *Shibata* (1902), he accepts especially the organisms causing nodules in Alnus and Myrica roots as true actinomycetes. *Bottomley* (1912) and *Spratt* (1912), on the other hand, isolated *B. radicicola* from Alnus, Myrica, and Elaeagnus nodules and see in it the causative agent. This point needs further investigations, which probably will best start again from the experiments carried on by *Hiltner* (1898), who obtained from Alnus nodules thin rods, which grew in an actinomyces-like arrangement. That *B. radicicola* exhibits all marks of the *B. pneumoniae-coli* group can be easily ascertained by comparative studies (*Löhnis*, 1905 *a*) and that all members of this group show branching under suitable conditions, is beyond dispute.[1] In addition, it will become apparent from the further discussion of these points in the following chapters that other characteristics, also accepted by many as necessitating a separate systematic position of the nodule organism, can be generally found with the bacteria as soon as these are made the objects of adequate

[1] Data concerning the branched forms of *B. radicicola* may be found in the publications of *Morck* (1891), *Dawson* (1899), *Hiltner* and *Störmer* (1903), *Süchting* (1904), *Harrison* and *Barlow* (1907), *Rossi* (1907), *Buchanan* (1909), and of *Gage* (1910). That they are erroneously classed as "involution" forms has been discussed on p. 25.

studies. The relations to the vibrios, already indicated by some peculiarities of other members of this group, as mentioned above, are equally discernible with *B. radicicola* and its next kinsman, *B. radiobacter*. It is well beyond doubt that the organism described by *Severin* (1897) as *Vibrio denitrificans* is nothing else than a denitrifying strain of Radiobacter (see *Löhnis*, 1910, p. 486). The characteristic triangular forms found with it, like with all vibrios and spirilla, have been well drawn by *Bordoni-Uffreduzzi* (1888) in his sketch of "Proteus hominis capsulatus" (reproduced as fig. 14 on Plate D). A good survey of the different types of growth of *B. radicicola* has been given by *Conn* (1909) in the drawing reproduced as figure 16 on Plate E (from original fig. 26, p. 99). That the flagellation has been found to be either mono- or peritrichous agrees well with the analogous behavior of other members of this group, as mentioned above.

Bact. rubiacearum, the organism causing nodules in the leaves of tropical Rubiaceae, was found by *Faber* (1912) to resemble *B. radicicola* very closely. Again the branched forms are prevalent in young nodules, and their ability to produce small coccoid bodies, which reproduce the "normal" rods, is the same as in the case of the legume organism. Results obtained by *Georgevitch* (1916) confirm these findings. The causative agent of crown gall, *Bact. tumefaciens*, gives a similar branched growth (*E. F. Smith*, 1911, Vol. II, p. 73).

Among the pigment forming rods some producing a yellow color show distinct relations to the *B. coli* group. *Fr. Levy* (1904) isolated two Coli varieties from flour, of which the first one (*B. coli albido-liquefaciens*) deviated from the type by its inclination to liquefy gelatin, while the other one (*B. coli luteo-liquefaciens*), in addition to this, produced a yellow pigment. While, however, both still possessed the typical fermentative abilities of the Coli group, another strain, isolated from the same source, resembled closely the second one, morphologically as well as physiologically, except that the production of gas was absent. An interesting counterpart to this organism is presented by an old stock culture of *Schroeder's Bact. synxanthum*, studied by *Lehmann* and *Neumann* (1912, p. 392, footnote). Originally a motile yellow short thin rod, producing alkali and staining milk yellow, it was found to be an immotile slime producing organism, Gram-positive in 1899, Gram-negative in 1903, growing like *B. coli* on gelatin, agar, and in milk, which was coagulated; gas was produced from glucose, and only on potato a bright yellow pigment still appeared.

Bact. Fraenkelii, isolated by *Hashimoto* (1899) from milk, is another yellow rod which has been frequently cited as a prominent example of pleomorphism. Growing on agar as small rod with 2–3 polar flagella, it forms in broth long chains of thick immotile globules, looking just like large streptococci. These divide transversely, as well as longitudinally, which leads to "pseudo-ramification." Sarcina-like formations were also seen.

Distinctly Actinomyces-like branching seems to have been observed with yellow rods only twice, i. e., with *B. erythrogenes*, according to *Migula* (1900, Vol. II, p. 458), and with *Bact. solare*, according to a report made by *E. Wolff* (1898). That this occurrence is no reason (contrary to the opinion of the latter author) to remove this organism to the Actinomycetes has been discussed (p. 23). A "Streptothrix polychromogène," described by *Valée* (1903), exhibiting the same rather unique double-pigment production as the first-named species (soluble red, insoluble yellow), perhaps is to be united with *B. erythrogenes*.

Bact. prodigiosum, originally mistaken by *Cohn* for an immotile micrococcus, has been frequently studied with regard to the variability of its pigmentation; its morphology, on the other hand, has been much neglected, though as early as in 1888 *Wasserzug* (1888 *a*) has demonstrated that it, too, can exhibit great differences on various substrates. Besides rods and threads, typical staphylococci, as well as spiral forms, were produced. Large globules (1–2 μ) and yeast-like cells have also been seen. *Slater* (1891) observed with another Prodigiosus variety, which he named *B. corallinum*, that the long threads present in liquid substrates, exhibited a marked tendency to form bud-like projections, which in some instances became so prolonged as to resemble branching. His drawings remind one at once of the branched forms of *B. radicicola* and related organisms. *N. G. Davis* (1901) in the course of studies upon the pigment production of *B. rosaceus metalloides Dowdeswell*, got, after hundreds of replatings, typical cocci

(of 0.5μ diameter) which further remained constant. *Ph. Eisenberg* (1914) says that the morphological alterations exhibited by *B. prodigiosum* are "not conspicuous, usually inconsistent, and not uniform." It seems, however, as if here, like in many other cases, very much attention was spent upon the appearance and disappearance of the red pigment in the cultures and only very little interest was left for microscopical studies.

Bact. violaceum is another instance where *F. Cohn* used a rod for establishing his "genus" Micrococcus (see p. 11). That temporarily globular forms occur also with this organism was probably first mentioned by *Zopf* (1883, p. 68). A related, immotile, slime-producing form, called *Bact. visco-fucatum*, was isolated from butter by *Harrison* and *Barlow* (1905), who found that "elongated branched and cuneate forms were common in old cultures, kept at temperatures below 25° C., and in young cultures at temperatures above 27° C., and in certain special media. These cells were 4–9μ long and up to 0.9μ wide. The cuneate forms were 0.9μ at the larger and 0.3μ at the smaller end. The branched forms were frequently complicated and sometimes tangled together, reminding one of a clumping formation. After the branched forms had become numerous, they broke up by transverse segmentation into short oval elements."

The pleomorphism of the colonies of *Bact. syncyaneum* and of other lophotrichous organisms has been fully studied by *Nyberg* (1912). Thorough experimenting showed that it was possible to induce every one of 140 strains tested to grow either in smooth and round or in wrinkled and branched colonies. Other biological, as well as morphological, differences were correlated with this dimorphism, but they were not made the object of special investigations.

With *B. pyocyaneus* it has been shown by *Guignard* and *Charrin* (1887), a long time ago, that conspicuous alterations in the morphological appearance, as well as in the physiological behavior, can be evoked by slight changes in the substrate (viz., by adding small amounts of antiseptics, like boric acid, phenol, creosote, and thymol). The rods passed over into threads, these into spirilla, which later formed round resting forms, which in their turn were able to reproduce the typical rods. The spiral forms did not produce pyocyanine, but the rods germinating from their resting forms, proved to be normal also in this respect. It is, on the other hand, of course, not very difficult to suppress or alternate the pigment formation more or less permanently also with this organism. *Charrin* and *Roger* (1887) made such experiments with Pyocyaneus, as well as with *B. fluorescens*. As did small quantities of antiseptics, exclusion of air also caused a change from the brilliant bluish green to a light yellowish color. A constantly colorless variety of *B. pyocyaneus* was obtained by *Charrin* and *Phisalix* (1892) by cultivating at 42.5° C. After several transfers the alteration was stable also at lower temperatures, but one passage through the animal reestablished the typical character. A special publication upon pleomorphism and pleobiosis of *B. pyocyaneus* has been contributed by *Schürmayer* (1895). In broth both thick short rods and very thin long threads were observed. *Gamaleia* (1900) noticed that branched forms became frequent with *B. pyocyaneus*, as with other species, by adding lithium compounds to the substrates. *Wassermann* (1903) classes *B. pyocyaneus* among the "pleomorphous schizomycetes," and *Péju* and *Rajat* (1906 *f*) as well as *Wilson* (1907) found that potassium iodide and urea favored the appearance of the different stages of growth also in this case.

Some data upon the different cell forms produced by *B. fluorescens* in the various phases of its life cycle are to be found in *W. Winkler's* (1899) and in *Fuhrmann's* (1906–1908) papers. That all four principal cell forms, viz., small and large cocci, as well as small and large rods may sometimes be encountered in the same microscopical field, was shown in one of the photographs of our second preliminary communication (*Löhnis* and *Smith*, 1916 *b*), reproduced as figure 48 on Plate IV. Curved forms, as well as star-like growth, are equally frequent with this species. The denitrifying Fluorescentes, described by *Christensen* (1903) as "new species," are evidently strains of *Bact. putidum*, exhibiting the same pleomorphism: small cocci and rods (0.5–1.0$\times$0.5–1.5μ) and large cocci, ovals and rods (1.25$\times$1.5–3μ, occasionally up to 4–5μ)

Pseudomonas cerevisiae, whose life cycle was partially investigated by *Fuhrmann* (1906), probably also belongs in the neighborhood of *B. fluorescens*. The same holds true for the

so-called *Bact. bruneum*, i. e. a brown variety of *B. fluorescens*, whose sarcina-like regenerative bodies were photographed by *Matzuschita* (1900), and reproduced as figure 18 on Plate II. An organism first called by *Rullmann* (1897) *Nitrosobacterium*, because of the erroneous assumption that it might participate in the process of nitrification, and later (1898 *b*, 1900) changed by him into a *B. ferrugineus*, is another brown variety of *B. fluorescens*, producing in mineral solutions thin branched threads, often showing terminal inflations; but on agar at 37° C. big "involution" forms were seen to grow up to $1.2 \times 7\mu$.

That the genuine nitrite and nitrate-producing organisms, *Nitrosomonas* and *Nitrobacter*, are also distinctly pleomorphous has been already pointed out by *Winogradsky* (1892), whose attention, however, was especially attracted by the differences distinguishing the "zoogloea" and the motile stages of Nitrosomonas. As the discussion of the true nature of this "zoogloea" will be taken up in Chapter III, the "monas" stage only will be considered here.

Winogradsky was of the opinion that the Russian Nitrosomonas (from Kasan soil) should be accepted, on account of its smaller size, as a species different from the larger Nitrosomonas from Zürich, and also different from the Nitrosomonas from Java, which developed large and small cells at the same time. A comparative study of *Winogradsky's* photographs, however, shows clearly that the Nitrosomonas of Zürich (original fig. 1, reproduced as fig. 49 on Pl. V) has by no means a uniformly large size; small cells are budding forth from and are interspersed between the larger bodies. The Nitrosomonas from Kasan (original fig. 4, reproduced as fig. 50 on Pl. V), on the other hand, displays mostly small forms, but large cells are also present, and their breaking up into small ones by dividing and budding is equally clearly represented. The Nitrosomonas of Java (original fig. 12, reproduced as fig. 51 on Pl. V) evidently takes its place exactly in the middle between both other forms as photographed; here an even mixture of large and small forms is to be seen. *Winogradsky* himself declares the larger cells in this case to be "small colonies of the small forms," a statement which undoubtedly is equally applicable to the Zürich organism. That the morphology of Nitrobacter follows similar lines is to be seen from a comparison of figs. 52 and 53 on Plate V (original figs. 1 on Pl. XVIII, 1891, and 16, 1892). Whether, however, the so-called *Nitrobacter polytrophum* actually represents, as *Beijerinck* (1914 *b*) asserts, a polytrophous modification of the *Nitrobacter oligotrophum*, must be left in doubt. The fact that this new "modification" differed rather radically, morphologically as well as physiologically, from the true Nitrobacter, and that it could not be reverted within 10 years into the original nitrifying form, makes it very probable that some contamination has played its rôle in this as in many other cases, among which the creation of the "Salpeterpilz" by *Stutzer* and *Hartleb* (1897) probably is the best and at the same time the most unfavorably known example. These authors had later (1899 *b*, 1901 *a*) results which agreed fairly well with those of *Winogradsky;* they proposed, however, a new name—"Nitromicrobium" for Nitrobacter—because they noticed the occurrence of budding (visible also in *Winogradsky's* pictures) and thought erroneously that bacteria never show this kind of propagation. Their "Hyphomicrobium" obtained at the same time in their nitrification studies (1899 *a*), which grows either as short motile red, or as thin branched thread, producing round regenerative bodies, and also thought by them to be no bacterium, may have been identical with *Beijerinck's B. oligocarbophilus*, which has been recently removed by its author (1914) into a new genus Actinobacillus, which is closely related to Actinomyces. The colonies are very much alike, especially with regard to the formation of aerial hyphae. Actinobacillus is, according to *Beijerinck* (1914 *b*), devoid of branching, which statement, however, may be justly doubted.

The Actinobacillus found by *Lignères* and *Spitz* (1902) to be the causative agent of the peculiar "Actinobacillose" of South American cattle, also exhibited only coccoid and rodlike cells in the cultures, but the clusters occurring in the pus are made up of richly branched forms, looking like *Metchnikoff's* (1888 *b*) *Pasteuria ramosa*. Th. *Smith* (1918), on the other hand, obtained a pleomorphic bacillus from pneumonic lungs of calves which grew in the tissue only as a fine rod, while in serum cultures flakes with large clubs and also coccoid forms were produced. The author rejects the term Actinobacillus, which he desires to replace by the name *Bacillus actinoides*.

(c) SPORE-FORMING RODS.

Among the early bacteriologists the opinion was rather generally adopted that the spore-forming bacilli do not permanently appear as large rods, but are also able to assume temporarily coccoid shapes. *Perty* (1852), e. g., pictured his *Metallacter bacillus* (on his Pl. XV, fig. 26 *a*) in the manner reproduced in figure 17 on Plate E. *Nägeli* (1877) illustrated his statement, that *F. Cohn* was "fundamentally wrong" in assuming that the bacilli be always long rodlike cells, by a similar drawing, reproduced as figure 18 on Plate E (from original fig. 2). *Buchner* (1882, p. 221) gave another interesting picture, reproduced as figure 19 on Plate E, showing once more that coccoid, as well as rodlike, forms can both be produced by the same organism.

All recent studies have confirmed and amplified these early findings. Many details pertaining to different aerobic species, which were made the object of comparative investigations, may be found in publications by *Gottheil* (1901), *Neide* (1904), *Gruner* and *Fraser* (1912), *Ford* (1916), and others. The large, globular, granular cell forms, described by these authors, are quite similar to those considered to be characteristic of Azotobacter. Their appearance was not stimulated by potassium iodide and urea—i. e., those two substances which *Péju* and *Rajat* (1906) found to be very useful in bringing about analogous changes with several nonspore-forming rods. Branching was observed by *Gottheil* (1901, p. 717), especially with *B. cohaerens*. It takes place, according to *A. Meyer* (1901), earlier than the spore formation, or under conditions which favor the formation of long threads and hinder the production of endospores. That neither the large coccoid nor the branched forms should be classed as "involution forms," has been discussed (on p. 24–27). That motility and flagellation here as in other cases can not be considered to be of fundamental importance for systematic purposes, may be seen, e. g., from a paper by *Ellis* (1906) upon "The Life History of *Bacillus hirsutus*." *Henrici*, who established this "new species," found it immotile, while it showed to *Ellis* at first polar cilia like a "Pseudomonas," but later the peritrichous flagellation of a "regular" bacillus became visible. An old stock culture of *B. implexus*, described by *Zimmermann* as immotile, assumed motility and so became, according to *Zierler* (1899), a typical *B. subtilis*. *B. mycoides*, on the other hand, when studied by *Lehmann* (1899), refused for a long time to show any motility and most of the rods remained, despite prolonged experimenting, permanently immotile.

Very interesting results with *B. mycoides* have been recorded by *Olsen* (1897), as well as by *Nadson* and *Adamovič* (1912). The first-named author noticed that aerobic spore-forming bacilli are much inclined to produce yeast-like forms. When cultivated on wet sand and gravel, *B. mycoides* gave a white dry growth on the surface, which in carefully made preparations showed itself to be made up of frequently branched Actinomyces-like cells, forming short plump "pseudoconidia," which very easily broke off. In the liquid, however, only "normal" rods and threads became visible. Figure 20 on Plate F is a reproduction of figure 14 on Plate V of *Olsen's* publication, illustrating these findings. *Nadson* and *Adamovič* (1912) obtained a typical Actinomyces-like growth of *B. mycoides* by adding to broth and agar equal amounts of an old liquefied gelatin culture of *B. mycoides*, which was previously sterilized by being kept 15 minutes at 120° C. Further transfers remained constant; they were unable to produce spores and to dissolve the gelatin.

Some of the forms in *Olsen's* sketch resemble very closely certain types of growth of diphtheroid and tubercle bacilli. It is worth mentioning in this connection that *Niessen* found a Gram-positive diphtheroid "streptobacillus" in syphilitic lesions which is slowly motile, produces typical endospores, shows branching and budding, and appears in small, as well as in large, globular and rod-like forms. The "*Cladothrix stereotropa*," isolated by *Proca* and *Danila* (1910) from the same source is either identical or closely related to *Niessen's* "streptobacillus." Here again the diphtheroid character is very distinct, yet there are motile rods, too, which form endospores, and also globular immotile, budding cells. A pleomorphic bacillus, obtained by *H. U. Williams* (1912) from a case of tuberculous pericarditis, is another diphtheroid, although spore-forming, evidently belonging to this group. And the same may hold true with regard to *Mycobacillus synovialis*, isolated by *Chantemesse, Matruchot* and *Grimberg* (1917), from a case of arthritis. It is a spore-forming bacillus, producing a salmon color in milk and

on potato, much inclined to produce in the cultures branched threads, and therefore accepted by its discoverers as a connecting link between the sporulating bacilli and the actinomycetes.

That *B. anthracis* is not always so constant and monomorphous, as was proclaimed by *R. Koch*, has been shown first by *Buchner* (1882 *a–c*), who succeeded in changing its morphological, as well as physiological, behavior to such an extent that it became very similar to *B. subtilis*. By adding relatively large amounts of sugar, both organisms could be induced to produce distinctly isodiametric cells. *E. Klein* (1883) got similar round forms of 1.3–2.6μ diameter in chain-like arrangement, or sometimes still connected with typical rods and threads, when *B. anthracis* was cultivated in pork broth or pork-broth gelatin, kept at 20–25° C. They either multiplied by dividing into two or four, or by true budding. Their virulence against guinea pigs and rabbits was the same as that of the rods. The latter always reappeared in the animal and could also be obtained from the round cells in artificial culture. The picture given by *E. Klein* (as figs. 1–3 on Pl. XXI) and reproduced as fig. 21 on Plate F, makes it practically certain that, if not all, at least most of these round cells have been microcysts or regenerative bodies. Another drawing, published a few years later (1885) in *Klein's* textbook on pathogenic micro-örganisms and reproduced as figure 22 on Plate F (from original fig. 77, p. 109), also deserves our attention. Here again the character of reproductive organs is fairly well indicated. *Klein* himself places these cells parallel to the "sporangia of nostoc algae." Others of the round cells, however, seem to be of a truly vegetative nature. In a later paper *E. Klein* (1894) reports that he noticed, when studying very early phases of growth of *B. anthracis* "when the colonies are only just visible as angular greyish spots," that the sprouting filaments at the edge were made up of spindle-shaped and oval elements with much vacuolization. His pictures (original figs. 1 and 2 on Pl. I) are reproduced as figure 23 on Plate F. After 4 days only typical straight rods and threads were found.

De Bary (1884, p. 504) saw also anthrax bacilli change into large cocci, but he was unable to secure satisfactory proof of further development. Analogous results were obtained by *Braem* (1889) by keeping anthrax bacilli in distilled water. Good pictures of the different appearance of this species in artificial cultures and under natural conditions were given by *Itzerott* and *Niemann* (1895, original figs. 13–15). They are reproduced on Plate V as figure 54 (from gelatin), figure 55 (from blood, mouse) and figure 56 (from spleen, mouse). All photographs were made with the same magnification (× 1,000), and the smears were all treated in the same manner (stained with methylene blue). *Crookshank* (1896, p. 195) reported that especially from gelatin and glycerin agar "very striking preparations are sometimes obtained with numerous large spherical and lemon-shaped elements." The same facts were described by *Rodet* (1894, p. 18 and 25), as follows:

> À côté de filaments réguliers . . . d'autres présentent des renflements, des dilations et, intercalés aux articles cylindriques, des articles courts et plus ou moins arrondies . . . Articles . . . véritablement sphériques . . . sont alors entremêlés à des éléments moins modifiés et c'est toute une gamme entre les filaments les plus reconnaissables et ces formes singulières qui donnent l'impression de la présence accidentelle d'un microbe étranger.

The round forms which *Matzuschita* (1900) found on salt agar, together with normal spores, are reproduced on Plate V as figure 57 (from original fig. 31). As far as can be judged from sight, they are typical regenerative bodies. Some of them exhibit the budding already observed by *E. Klein*. *Lignières* and *Durrieu* (1902) noticed that a very virulent strain of *B. anthracis* changed on agar within 4 days into long filaments producing round buds or assuming irregular spiral shape, while on potato a yellowish growth appeared, made up of pear- and club-shaped cells. Some other interesting proof of the pleomorphism of *B. anthracis* was secured by *Mme. Henri* (1914) by treating a watery suspension of the bacilli with ultraviolet rays. Most of the cells were either killed or remained normal; but some of them gave colonies of such forms as are reproduced on Plate V in figure 58 (from original fig. 4), which are very similar to those seen by *E. Klein* and *Matzuschita*. That they were regenerative bodies was proved in this case by their reverting back to normal rods. Sometimes, however, *Henri's* experiments led to a stabilizing of the spherical growth. The typically coccoid cells reproduced in figures 59 and 60

on Plate V (from original figs. 5 and 6) did not go back to the rod form. Moreover, an actinomyces-like growth developed, made up of branched, Gram-negative, nonsporulating filaments, shown in figures 61 and 62 on Plate VI (from original figs. 7 and 8), which resemble very much the atypical growth of *B. mycoides*, obtained by *Nadson* and *Adamovič*. These filaments did also not revert to the rod form directly, but only after having formed again the coccoid regenerative bodies, reproduced in figure 63 on Plate VI (from original fig. 9), which process agrees closely with the behavior exhibited by *B. azotobacter* and other organisms tested in our own experiments (1916), when passing over from one subcycle into another.

With *B. subtilis* similar round forms were studied by *Buchner* (1882) and by *E. Klein* (1885, p. 110). The photographs of *B. subtilis* reproduced as figures 64 and 65 on Plate VI from our preliminary papers (*Löhnis* and *Smith*, 1916 *a*, fig. 26; 1916 *b*, fig. 6) make interesting counterparts to those of *B. anthracis*, as well as to the well-known pictures of "bacteroids" of *B. radicicola*. Distinctly filamentous growth, resembling Actinomyces, has also been obtained.

An old stock culture of the so-called *Tyrothrix tenuis*, originally isolated by *Duclaux*, gave us (1916 *a*) very similar results as did *B. subtilis*. *W. Winkler* (1895), who tested several of *Duclaux's* "Tyrothrix" cultures, speaks also of broad "involution" forms, which probably have been of the same nature, as far as can be judged from his paper and from his drawings. Analogous findings were recorded by *Viehoever* (1913, p. 230) in regard to *B. Pasteurii*. The globular forms produced by segmentation of the rods, which he calls "micro-oidia," probably are to be classed as regenerative bodies like those obtained by *Henri* with *B. anthracis*. That the yeast-like "involution" forms, considered by *Miquel* and *Cambier* (1902, p. 633) as characteristic of *Urobacillus Maddoxii*, are actually not of such a distinctive value as these authors thought, needs no special discussion.

A bacillus isolated by *Pansini* (1890) from sputum and described as "No. 6" is another example of pronounced pleomorphism within the Subtilis-Mesentericus group. Small cocci, large yeast-like cells, and rods of different size have been recorded. With other bacilli from the same source "coccoid degeneration forms" were also registered by this author.

A bacillus found by *Maassen* (1904) in "Hackfleisch" gave branching under the influence of lithium salts added to the substrate. Figure 66 on Plate VI is a reproduction of the original figure 11 on Plate XIV. Practically the same development was shown by another not completely studied "yellow bacillus No. 41" from soil, used in our preliminary experiments on the life cycles of the bacteria (1916 *a*), in this case, however, without being stimulated by lithium or any other specific stimulant.

Gamaleia (1911, p. 211) found lithium salts equally useful for producing branched growth of *B. Megaterium*. The normal rods of this species, originally described by *De Bary* (1884, p. 500) as being 2.5μ broad, showed only a width of 0.6–0.8μ when reinvestigated by *Lehmann* and *Neumann* (1912, p. 461). It is to be expected that here again small and large cell forms may become visible, according to the subcycles entered by the organism in the course of its development. Long chains of big spherical cells have been also recorded by *De Bary* (1884, p. 503) for *B. Megaterium*, and it has been mentioned (p. 41) that the presence of a small bacterium was found to be distinctly favorable for inducing this transformation, just as was the case when *B. radiobacter* was growing together with *B. oxalaticus* or with a stable rod-like strain of *B. Azotobacter*. *Bac. danicus*, found by *Löhnis* and *Westermann* (1908) to be a common symbiont accompanying *B. radicicola* in the root-nodules of leguminous plants, seems to be influenced by the latter in an analogous manner. As with *B. Megaterium* and *Azotobacter* the reduction of size in pure cultures has been also noted in the case of *B. oxalaticus*. *Migula* (1900, Vol. II, p. 538) found that at first the rods measured $2\frac{1}{2}$–3×4–8μ; later, however, not more than $1.2 \times 1.8\mu$.

B. malabarensis, isolated by *Löhnis* and *Pillai* (1907) from East Indian soil, is of great morphological interest, not only because it is even more inclined than the species mentioned to assume distinctly Azotobacter-like forms, but also because of its liability to produce peculiarly looking beet-shaped, spermatozoon-like, and later long-tailed spindle-shaped cells, as are shown

in figures 67 on Plate VI and 266 on Plate XXI. These forms present a remarkable counterpart to the appearance of Rhabdochromatium, just as the large Azotobacter-like cells resemble those of Chromatium. Probably the natural relationship of these little known sulphur bacteria will be better understood, after the life history of the large spore-forming bacilli has been more completely studied. *Migula's* remark (1904, p. 31) that no such cell forms are to be found with typical bacteria can not be accepted as correct. And that the peculiar, swollen, and tailed cells can not be discarded as "involution" forms, is proven by the fact that they, too, precede the formation of spores. *Duclaux* (1883, p. 654) described this a long time ago, referring to the analogous behavior of his *Tyrothrix virgula*, with the following words:

> Ce renflement grossit pendant que la portion du bâtonnet qu'il n'a pas atteinte se résorbe et s'amincit de plus en plus, de sorte que l'être tout entier prend des formes très singulières . . . Quelques-uns d'entre eux rappellent d'une manière frappante des spermatozoïdes. C'est dans les renflements que se fait ensuite le travail de formation des spores.

Bac. Baccarinii, isolated by *Macchiatti* (1898) as a causative agent of the "mal nero" of the grapevine, is another example of distinct pleomorphism among the spore-forming bacilli. From typical cocci up to long threads practically all forms were seen.

Bac. tumescens shows the same character, as was first pictured by *Zopf* (1883, p. 66) in the drawing reproduced as figure 24 on Plate G (from original fig. 23), and later studied anew by *A. Koch* (1888) and by *Garbowski* (1907). The last-named author made at the same time a fairly complete study of *Bac. luteus sporogenes Wood* et *Baker*, which led to many confirmative results. Good branching has been recorded in this case, as well as the formation of those small coccus forms (of only 0.8–1μ diameter), which simulate very much streptococci and sarcinae, and which have been described as "micro-oidia" by *Bredemann* (1909) for *B. Amylobacter*, and by *Viehoever* (1913) for *B. Pasteurii*.

That all the different species or varieties of the Azotobacter group are probably types of growth of spore-forming bacilli, is indicated by the results of our more recent investigations (*Löhnis* and *Hanzawa*, 1914, L. and *Smith*, 1916). Several of the photographs accompanying our 1914 paper present interesting counterparts to those published by *Henri* at the same time for *B. anthracis*. Especially the small round Azotobacter cells (regenerative bodies) reproduced as figure 68 on Plate VI (from original fig. 28) look very much like *Henri's* Anthrax cells in figures 59 and 60 on Plate V. Figure 69 on Plate VI (reproduced from *Löhnis* and *Smith* 1916 *a*, fig. 20) demonstrates, in addition, that it is possible to induce a strain, which originally showed the typical character of Azotob. chroococcum, to grow in a manner very much resembling that of the normal *B. anthracis*. Fig. 70 (reproduced from *Löhnis* and *Smith* 1916 *a*, fig. 16), on the other hand, represents an interesting intermediate stage in the development of small rods, in which case *B. azotobacter* assumes forms very similar to *B. radiobacter* and other organisms belonging to the *B. pneumoniae* group. A comparison of fig. 70 with figs. 38 and 39 on Plate IV, illustrating the analogous stage in the life cycle of *B. pneumoniae*, will further prove this fact. (The clusters visible in fig. 70 are the outgrowths from the symplasm, to which reference will have to be made in Chapter III.) Figures 71 and 72, taken from a paper by *Walton* (1915, original figs. 1, 9 and 10) show the small short rod-like forms from a one day old culture, and the typical large Azotobacter cells from the same culture after 7 days growth. Most of the strains studied by this author underwent an analogous change regularly, though in other cases the small forms have proved themselves to be much more persistent. The pleomorphism of *B. azotobacter* was already noticed to some extent by *Beijerinck* (1901 *b*). More data were furnished by *Düggeli* (1905 *a*), *H. Fischer* (1905), *Löhnis* and *Westermann* (1908) and by *Krzemieniewski* (1908). Branched forms were first seen by *H. Fischer* and by *Löhnis* and *Westermann;* but they were considered by the first-named author to be "involution" forms. *Peklo* (1910) supposed that as *B. radicicola* and spore-forming bacilli, so also Azotobacter be related to the Actinomycetes. Of special importance are *Prazmowski's* (1912) extended investigations upon morphology, cytology, and physiology of the Azotobacter group, which were further confirmed and amplified by the studies made by *Löhnis* with *Hanzawa* (1914) and with *Smith* (1916).

Our first preliminary report upon the life cycles of the bacteria (1916 *a*) contains the description and pictures of most of the various types of growth of *B. azotobacter*. A schematic sketch of the complete life cycle of this organism was reproduced from the last-named paper as figure 1 on Plate A; and on page 36 two tables were reprinted, showing that essentially the same complex morphology was not only observed with all Azotobacter strains tested, but that it could also be traced in all other groups of the bacteria.

Harrison (1900) has described variations in size and shape, as well as the appearance of Y forms, with *B. alvei*. Like other species connecting aerobic and anaerobic spore-forming bacilli, it seems to be much inclined to lose its ability to form spores, as was noticed by *Lehmann* and *Neumann* (1912, p. 505).

Pleomorphism and pleobiosis of the more or less strictly anaerobic bacilli have been firmly established, especially by the investigations of *Grassberger* and *Schattenfroh* (1900–1907) and by *Bredemann* (1909). It remains to be seen, however, whether or not the study of the complete life cycles of these organisms will support the standpoint taken by the latter author, who is of the opinion that a considerable number of anaerobic species, mentioned in the literature, should be cancelled and united with *B. amylobacter*. That as with aerobic, so also with anaerobic spore-forming bacilli the morphological changes can not be stimulated in the same manner as with various nonspore-forming bacteria, i. e., by adding potassium iodide and urea, was reported by *Péju* and *Rajat* (1906 *e*). Change in motility and cell form of *B. amylobacter* has already been seen by *Van Tieghem* (1884, p. 110). Besides rod-like forms, "cellules sphériques et ovoides" and others "enroulées en helice" were mentioned, all of which were found to be able to produce spores. Analogous results have been recorded by *Prażmowski* (1880) for his Clostridium butyricum and Polymyxa. His drawings, reproduced as fig. 25 on Plate G (from original figs. 1, 2, 6, and 7 on Pl. II), illustrate that he saw changes between "Clostridium" and "Plectridium" type, formation of curved, coccoid, and large inflated cells and in the accompanying text it was especially pointed out that the last-named form became visible when the development of luxuriantly growing cultures was at its height, so that they should not be classed as "involution" forms. They were seen to return to the normal rod form by segmentation. Spherical cells were observed by *Prażmowski* only with his Clostridium Polymyxa, but it was, indeed, quite probable, as *Zopf* (1883, p. 70) presumed, that they would also be discovered with Clostridium butyricum. As mentioned above, *Van Tieghem* has seen them, and in figure 26 on Plate G drawings from *Bredemann's* paper on *B. amylobacter* (1909) have been reproduced, showing the forms called by him "micro-oidia." They were found with all of his strains and under quite suitable conditions, but he was unable to revert them into the typical rod-like anaerobic growth. On aerobic plates they gave small soft punctiform colonies.

The results obtained by *Winogradsky* (1902) with his Clostridium Pasteurianum are very similar, and *Bredemann* includes this "species" among the varieties of *B. amylobacter*. As figure 73 on Plate VII one of *Winogradsky's* photographs (original fig. 3) has been reproduced, showing large and small coccoid forms, curved cells and apparently also some branching and budding. The morphological, as well as physiological, variability was found to be so great with this species that the different strains were hardly recognizable as being of the same kind.

The behavior of and the relationship existing between the various anaerobic butyric acid, pathogenic, and putrefying bacilli have been fairly well elucidated by the investigations of *Schattenfroh* and *Grassberger* (1900), of *Grassberger* (1902–1905), and of *Grassberger* and *Schattenfroh* (1907). Motility and cell form, but also appearance of colonies and physiological character, exhibit very wide variabilities. Some strains are comparatively stable, while others are easily "denatured," which expression is used by the authors for those cultures which have lost, temporarily or permanently, their motility and their faculty to form spores. As among the latter sometimes the production of gas also ceases entirely, and the butyric acid is largely replaced by lactic acid, the general character of such strains becomes very similar to that of certain lactobacilli. As I have pointed out (1910, p. 200) this transformation deserves to be investigated more thoroughly. *Laxa* (1911) found that treatment with formaldehyde was very

efficient in bringing about such alterations, not only with butyric acid, but also with putrefying strains. Presence of sugar favors the production of swollen forms and stimulates the fixation of nitrogen in the same manner as it does with aerobic spore-forming bacilli, while substrates rich in albuminous substances increase the tendency to pass over into the putrefying plectridium type (*B. putrificus*).

B. putrificus, *B. oedematis maligni*, as well as *B. Chauvoei*, may all be, according to *Grassberger* and *Schattenfroh* (1907) and *Bredemann* (1909), merely adaptations of *B. amylobacter*. The results thus far collected make a thorough study of the complete life cycles of these organisms very desirable and promising.

Coccoid, lemon-, and club-shaped forms of the organism of symptomatic anthrax were observed in cultures by *Ehlers* as early as in 1884. His work was discredited by *Kitt* (1887), but later confirmed by *Grassberger* and *Schattenfroh* (1907). *Fraenkel* and *Pfeiffer* (1895), as well as *Piani* and *Galli-Valerio* (1895), dwelled upon the pleomorphism shown by this species in the tissue, where small and large rods, dumb-bell shaped and coccoid cells were found. As figure 27 on Plate H drawings of *Ghon* and *Sachs* (1903, original figs. 13, 14, 16–18) are reproduced to illustrate this point. Except the cells shown at the left side, which were taken from the muscle of a pigeon, all forms were grown on the agar plate. The small branched cells resemble certain lacobacilli very much. Two of *Grassberger's* (1903) photographs, reproduced on Plate VII as figures 74 and 75, may complete the picture. Figure 74 (from original fig. 54) gives an analogous mixture of small and large rods, as was shown in figure 69 for one of our spore-forming Azotobacter strains. And figure 75 (from original fig. 21, material taken from sugar broth) could be easily mistaken for a photograph of a typical Azotobacter culture. This parallelism is enhanced by the variability in motility, the instability of spore formation, by the shape of the colonies, and especially by the possibility, proved by *Grassberger* (1905), to adapt *B. chauvoei* to aerobic life with loss of pathogenicity. Several objections have been raised by *Hibler* (1908) against the work done and the standpoint taken by *Grassberger* and *Schattenfroh*. His own work, however, seems to be much more open to criticism. On Plate VII, as figures 76 and 77, two photographs of symptomatic anthrax are reproduced from his book, where they appear widely separated (on Pl. X, fig. 16, and Pl. XVI, fig. 7). Both show the characteristic big round cells accompanying the rods. But only in the first case *Hibler* is inclined to admit this pleomorphism, because here the material was taken from a pure culture. In the second case, representing the analogous development in the peritoneum of a mouse, he does not hesitate to state: "Die verschieden grossen dunklen kugligen Körper sind Granula aus aufgelösten Mastzellen, der unterste Phagozyt schliesst auch zwei solche Körner ein," though, of course, this statement remains entirely without proof, and the obvious likeness of the two photographs (despite the different, not exactly defined magnification) creates considerable doubt whether *Hibler's* standpoint was not too strongly influenced by the monomorphistic doctrine with its well-known simple (but unfounded) "explanations."

A good example of true branching of the oedema bacillus has been given by *Grassberger* (1903) in the photograph reproduced as figure 78 on Plate VII (from original fig. 42). The material used was taken from sugar agar. *Ghon* and *Mucha* (1905) isolated a closely related organism from a case of peritonitis, which in the peritoneal exudate first looked very much like *B. coli*. In sugar agar it proved to be highly pleomorphous. Besides the more normal cells, club-shaped, curved vibrio-like rods became visible, "und in grosser Menge Gebilde in den verschiedensten Grössen und Formen, die vielfach kaum noch als Bakterienformen angesprochen werden konnten." Branching was frequent in hydrocele fluid.

With *B. tetani*, *Kanthack* (1896) and *Kanthack* and *Connell* (1897) have seen branchings, especially in young cultures (18–24 hours old), while in old cultures these forms usually disappeared. Clubbed cells and mycelial growth also were recorded by the last-named authors. *Tavel* (1898) photographed budding and branching of a pseudo-tetanus bacillus from the intestine, but did not mention this fact in his paper. *Hibler* (1908) noticed that the characteristic drum-stick form of *B. tetani* became regularly visible in cultures several days old, while with younger material the spores were very often located in the middle of the rods, which not

infrequentre looked like clostridia. Substrates rich in carbohydrates produced such abnormal forms exclusively. Even in old cultures no plectridia appeared under such conditions.

The anaerobic Vibrio Rugula, whose spore formation has been closely studied by *Prazmowski* (1880) was placed by *Lehmann* and *Neumann* (1912, p. 156, footnote) in the neighborhood of *B. oedematis maligni*. In fact, it seems certain that this organism has nothing to do with the genus Vibrio, as it is accepted in the modern literature. *Dujardin* (1841, p. 218) placed it close to his *Vibrio* (now *Bacillus*) *subtilis*, and he pointed out already, that Vibrio Rugula grows either curved or straight, occasionally forming "fils alternativement droits ou flexueux." *Prazmowski's* drawings are reproduced as figure 28 on Plate H (from original figs. 10 and 11 on Pl. I). As this organism was able to decompose cellulose, and *Omelianski's* photographs of his anaerobic cellulose bacilli show the same curved cells with terminal spores, it seems correct to assume that this is the proper classification of "Vibrio Rugula."

(d) SPIRILLA AND SPIROCHAETS.

The question has not been definitely settled whether the spirochaets are to be considered to be true bacteria, or whether they should better have their place between bacteria and protozoa, or perhaps among the latter themselves. Morphological, cytological, as well as physiological, reasons have been submitted in favor of the latter view. *Prowazek* (1907*a*) mentions in this respect especially the ribbon-like structure, the undulating membrane, the longitudinal division and the sexual differentiation, which, as well as the cysts, in his opinion are never to be found with bacteria. *Keysselitz* (1907) adds that also the flexibility of the spirochaets should be accepted as a proof of their protozoal nature, because he considers bacteria to be always of a rigid structure. *Hölling* (1911) and *Klimenko* (1914) point to cytological reasons in favor of the protozoa theory. *Krzysztalowicz* and *Siedlecki* (1908), as well as *McDonagh* (1912–13), furnished many details concerning sexuality and reproduction, which would support this view. *Carpano* (1914) even believes the rosette-like arrangement, sometimes displayed by spirochaets, to be valid proof of their protozoal nature. *Novy* and *Knapp* (1906), on the other hand, emphasized that on account of their flagellation, transverse division, and other marks the spirochaets should be united with the bacteria. *Zettnow* (1906) took also his stand against the assumed longitudinal division, and he thought, in addition, to have obtained proof of peritrichous flagellation. This, however, was refuted by *Keysselitz* (1907), *Schellack* (1907–09) and *Fantham* (1908) as being an error, caused by a separation of the fibrils in the undulating membrane; but *Schellack* (1909), as well as *Dobell* (1912) and *Swellengrebel* (1912), have shown that the cytology of these organisms is the same as that of bacteria. Transverse division and other reasons are mentioned by the two last-named authors in favor of their opinion that the spirochaets should be placed as a special group among the bacteria. The studies of *Gross* (1912) and of *Meirowsky* (1914*b*) upon their modes of reproduction equally support this view. In addition, *Meirowsky* (1914*a*) has pointed out that the true branching found by him with all spirochaets tested, should be accepted as strict proof of their bacterial nature. It goes without saying, that he was mistaken in this direction. Nevertheless, it seems that an unbiased consideration of all items concerned, including especially the reproductive processes to be discussed in Chapters II–IV, will support the view that the spirochaets, or at least a part of them, show much more the general character of the bacteria than that of the protozoa. Some organisms now included in this group might perhaps be better separated and brought into closer connection with the protozoa. At present, however, where their life history is hardly much better known than that of the bacteria related with them, it seems more useful to take advantage of all the results collected so far, and especially of those which might be helpful in further investigations upon the life cycles of their bacterial kinsmen, the vibrios and spirilla.

Vibrio cholerae, though at first also declared by *R. Koch* and his pupils to be strictly monomorphous and absolutely constant in its activity as in its appearance, can now be considered to be one of the best known examples of a wide pleomorphism. It is very much inclined to assume all the form types of the old form genera of *F. Cohn*. As early as in 1885 its ability to

grow in gionular shape was discovered by *E. Klein* (1885*a*). He found that at room temperature, but not at 38° C., after several days the curved bacilli pass over into circular forms, which later split up lengthwise into two regular comma bacilli. *Ferrán* (1885) had analogous results in diluted broth (*Koch's* broth is declared by him to be too concentrated). He calls these round forms "oogones," and reports that observations in the hanging drop also revealed the presence of smaller round bodies which, as "pollinodes," fertilized the oogones. Later the oospores are said to have liberated granules in large numbers, which in their turn grew up to "corps muriformes," and that these have reproduced some long fine spirilla, which later subdivided themselves to typical vibrios. *Ermengem* (1885), who quoted these findings extensively, was only able to confirm the report of the Spanish author as far as the granules and the "corps muriformes" were concerned, and when one reads *Ferrán's* original report, wherein he comes to the conclusion that the cholera vibrio is a type of growth of a "Peronospora Barcinonae," it appears, indeed, by no means surprising that this work could not gain any acknowledgment among careful bacteriologists at that time. Yet, in the light of many other facts discovered more recently, and after separating facts from theories, it becomes very probable that *Ferrán* has seen nearly all of the complete life cycle of this organism. The data to be given in the next chapters upon gonidia, gonidangia, regenerative bodies, symplasm and conjunction, will elucidate and confirm many of his findings. That *Ferrán* also saw long fusiform threads containing granules in old cultures, and that he found it difficult to revert these straight forms to the normal curved rods, is another point of interest. Moreover, it should be mentioned that *Ferrán,* according to his report, was able to find all the different forms not only in his cultures, but also in the feces of diseased persons, as well as in the exudates from inoculated animals. *Babes* made also some observations upon morphological changes and on differences in the appearance of the colonies of the cholera organism as early as in 1885. *Klebs,* too, wrote in 1887 (p. 359): "in sehr zahlreichen Fällen enthält der Choleradarm nicht die characteristischen Kommaformen, sondern Modificationen derselben," and he mentions as such especially ovoid cocci and large globules.

Papers by *Dowdeswell* (1889–1890), as well as by *Schroen* (1891), have brought much confirmation to the discoveries of *E. Klein* and *Ferrán.* However, they also met the same fate, though the observations recorded therein were based on continuous microscopic observation of the living organisms on the warm stage. In addition to the forms mentioned, *Dowdeswell* described and made drawings of branched filaments and of large triangular cells, which only recently have been rediscovered and photographed. *Metchnikoff* (1894) got large dumb-bell shapes, showing lateral buds and branches, very similar to those which he first noticed with the bacilli of avian tuberculosis, when he grew the cholera vibrio in symbiosis with a white coccus. Cells looking very much like Actinomyces, small ovals, cocci, short straight rods, and spermatozoid-shaped bodies have also been seen by him, and the cholera organism was therefore classed as an "example frappant du pléomorphisme si répandu dans le monde des bactéries." *Gruber* (1894) pointed out that some strains differ widely from the typical cholera vibrio, either by their pointed ends, or by assuming the shape of nearly straight rods possessing 4–6 long polar flagella. Motility, appearance of the colonies, nitroso-indol reaction, as well as the behavior in the animal test, were all found to be more or less variable. *Gruber* pays also special attention to the "Vibrio Ivanoff" which at first was declared by *R. Koch* to be a genuine cholera vibrio; later, however, an "entirely different species." In their "Atlas" *Fraenkel* and *Pfeiffer* (1895) published a good picture of various forms studied by the authors mentioned above, which to them, however, are merely "involution" forms, because they came from a broth culture three weeks old. Their photograph (original fig. 99 on Pl. XLVIII) has been reproduced as figure 79 on Plate VII; the "crippled involution forms" stain well, while the "typical" vibrios are pale and dissolving. As figure 80 a reproduction from *Itzerott* and *Niemann's* "Atlas" (1895, Pl. IX, fig. 53) has been added, showing again what these authors term "involution" forms, though the very characteristic appearance and the great similarity of the cells visible in both pictures are certainly not in agreement with the assumed "degeneration."

Cunningham (1897) emphasized that "many vibrionic organisms under certain circumstances have the power of multiplying indefinitely in the form of cocci, diplococci, and short straight rods, although under other conditions they are capable of assuming typically vibrionic characters." And he adds: "This is a fact which is well known to everyone who has practically studied the subject." *Gamaleia* (1900, p. 207) obtained giant spirilla and globules within 24 hours, when he grew the cholera cultures in broth containing ½–1 or on agar with 1–2 per cent lithium chloride. *Nakanishi* (1901) noticed that the globules of *V. cholerae* and *Metchnikovii*, whose diameter was about four times as large as the width of a vibrio, reverted readily to the typical comma form, even if they were taken from cultures 15 weeks old. *Kohlbrugge* (1901*a*) got long branched filaments of the cholera organism in blood serum, which he (erroneously) described as "Cladothrix-like." By repeated inoculation into animals *Shibayama* (1902) even succeeded in developing strains producing constantly thin branching filaments, which, however, were quite avirulent. Most of the important results recorded by *Almquist* (1904–1917) will have to be discussed in Chapter II, as referring to reproductive organs and processes. His cultures gave also small and large coccoid forms, straight rods which morphologically resembled the typhoid organism, and much budding. One culture, mentioned in his 1916 paper, grew during two years constantly in coccoid shape, though still exhibiting the normal behavior in the agglutination test. *Maassen's* (1904) work contains interesting details concerning the stimulating effect of various salts in bringing about the morphological changes in the cholera vibrio, which to the author are merely "pathologic deformities." *Péju* and *Rajat* (1906*e*) found that 5 drops of their potassium iodide solution added to the cholera culture produced coccobacilli, while 8–9 drops gave long threads. *Hammerl* (1906) discovered spherical bodies of 1–6μ diameter and branched cells in many cases. They were present already, and sometimes exclusively, in young cultures; they could be transferred for weeks and months, and their motility was very pronounced. The author, therefore, correctly refutes the "involution" theory. *Horowitz* (1911) not only observed the same pleomorphism as recorded by the earlier authors, he reports also upon a very great variability of the agglutinability of his strains, which experiments, however, can not be accepted as conclusive. *Lehmann* and *Neumann* (1912, p. 513) say concerning the "atypical" forms of *V. cholerae:*

> Unter besonders günstigen Bedingungen . . . trifft man . . . vorwiegend kurzovale, kokkenartige Gebilde. . . . In salzarmen, besonders aber auch in sehr salzreichen Flüssigkeiten bilden manche Cholerastämme auffallend geblähte bis kuglige Formen, die vollkommen fortpflanzungsfähig sind. . . . Wir haben auch manchmal lange, schöne Fäden gefunden, die von Fluorescens nicht zu unterscheiden waren, in den nächsten Culturen aber wieder nur als lange dünne Stäbchen auftraten. Wirklich gekrümmte Formen waren selten. Dies Spiel zeigt sich bei einer echten Kultur aus Hamburg von 1892 stammend nun schon seit über 10 Jahren.

The most complete survey of the different types of growth exhibited by *V. cholerae* has been given by *Stamm* (1914). Some of his photographs are reproduced as figures 81–83 on Plate VII (from original figs. 2, 4, 5, and 15 on Pls. XI and XII, and figs. 1 and 2 from the text, p. 512 and 524). He cultivated 13 strains under comparatively natural conditions, viz., in water; 6 of them remained constant, while 7 changed in their morphological as well as in their physiological behavior to a considerable extent. They all lost their agglutinability, and they did not return to the original type within 30 months, if frequently transferred. Inoculations from old cultures, however, gave again curved forms. The cocci, though themselves not agglutinable, produced a rabbit serum which agglutinated the typical *V. cholerae*. 37 strains, isolated by *Popoff-Tscherkasky* (1914) during the Balkan war, and kept for 4–9 months without being transplanted, grew after the first reinoculation as a mixture of cocci, short rods, and vibrios. The next transfer on agar gave after 24 hours at 37° C. very large irregular threads, big globules, and large rods, but not a single vibrio. These forms replated on agar gave only colonies containing vibrios of somewhat larger size, which then again proved to be stable. That the appearance and disappearance of the different forms is the result of the various phases of the life cycle of the cholera organism has been ascertained by *Olsson* (1915) under *Almquist's* direction. Atypical wrinkled colonies always gave him immotile cells, but these could be changed back into the motile form producing the typical colony.

How the strictly monomorphistic view, as established by *R. Koch*, in regard to his "Komma Bacillus," has changed within the last 30 years, even among his collaborators and followers, may be seen from the following quotations: In 1892 *Friedrich* in volume 8 of the "Arbeiten aus dem Kaiserlichen Gesundheits-Amte" tried to deal effectively with all that had been discovered by authors like *Dowdeswell, Cunningham,* and others. As far as this was not in accordance with the "legitimate" findings of *R. Koch* and his pupils it was easily "explained" as plasmolysis, vacuolisation, granular decomposition, degeneration, or simply fiction. *Dowdeswell's* "claims" were "not to be taken seriously." Nevertheless, some alterations in the appearance of the colonies and cells, as well as in the pigment production, are admitted, though on account of their instability they were not accepted as true variation. In 1903 *Kolle* and *Kolle* and *Gotschlich* admitted that the morphological marks, except the "legitimate" polar flagellum, can not be considered specific. The same was declared to be true in regard to the colonies on the gelatine plate, which were mostly found to be dimorphous. Only the agglutination test was strictly upheld, and those cases discarded as not being cholera, where a quickly fatal disease, showing the symptoms of cholera, was caused by vibrios which were not agglutinated by the true cholera serum. In 1912 *Baerthlein* furnished another contribution in volume 40 of the "Arbeiten aus dem Kaiserlichen Gesundheits-Amte" wherein now, however, the "mutation" of *V. cholerae* and of other bacteria was discussed extensively. Three types of colonies made up by different cell types were found and also traces of a cyclic development were discovered. Additional data upon this subject were published by *Feldmann* (1917) and by *Baerthlein* (1918).

As was mentioned on page 56, *Pollak* (1913) obtained colonies and cells looking like those of *V. cholerae,* when cultivating *B. faecalis alcaligenes* on the blood agar recommended by *Dieudonné* for cholera diagnosis.

The life cycle of the vibrio isolated by *Finkler* and *Prior* (1884) from cases of cholera nostras, which was named by *Buchner* on account of its pleomorphism *V. proteus,* received a fairly complete description by its discoverers already in 1885. Their very interesting, although frequently doubted, observations upon the reproductive processes will be quoted in Chapters II and III. The curved form was found to occur only temporarily. It was soon replaced by big globules, thin and thick rods, club-shaped cells, and other forms very similar to those observed much later also with *V. cholerae.* The ends of the curved cells were either rounded or pointed, sometimes their appearance was different at the same cell. *R. Koch* (1884 *b*) defended the "strictly specific" nature of his "Komma Bacillus" strongly against *Finkler* and *Prior,* whose findings were discredited as being the result of experiments with impure cultures. The last-named authors, however, could point out in return that *Koch's* own slides exhibited also a much greater pleomorphism of the cholera organism than this author was willing to admit. *Ermengem* (1885), too, did not hesitate to take his stand against *Finkler* and *Prior,* because differences in the appearance of the colonies and the cell form were to him full proof of "impurities." *Firtsch* (1888), on the other hand, showed soon that unquestionably pure cultures of the Finkler-Prior vibrio are able to produce four clearly different colonies, which, if found alone, undoubtedly would be considered to be those of four different species. Motile and immotile comma forms, spirals, straight rods, spindle-shaped, ovoid, and monad forms were again present, and *Firtsch* succeeded in many cases to change experimentally the various types of cells and colonies into each other. That his observations and conclusions were correct has been proven more than 25 years later by *Fürst* (1914), who with single-cell cultures secured analogous results. The different cell forms remained so constant, when frequently transferred to fresh substrates (after 5–6 days), according to standardized laboratory rules, that they could be easily mistaken for different species. When kept for 2½ months and then reinoculated many of them reverted to the original vibrio type. And 4-months' old cultures gave 100 per cent normal cultures.

Bonhoff (1896) isolated an organism from cholera nostras which first appeared very much like *B. coli,* macro- as well as microscopically. Later, however, it assumed comma, S and screw forms, while other cells presented themselves as diplococci. The rods possessed two polar flagella, representing an interesting connecting link between Vibrio and Pseudomonas.

E. Klein (1905) met in Cardium edule a pathogenic "Vibrio cardii," which he places between *V. cholerae* and *V. Finkler-Prior*. On agar, gelatin, and serum it forms abundantly convex and globular cells, which retain their motility and propagative ability, and they are declared to be very similar to those found before by the same author in cases of true cholera.

Kohlbrugge (1900) described a "new" vibrio from water under the (preoccupied) name *V. proteus*, which grew on agar as a short rod, in gelatin and broth as a vibrio, and in water as a coccus. Tested later (*Kohlbrugge*, 1901 *a*) on blood serum, it produced long branched threads as did *V. cholerae*. Another pleomorphous vibrio from water was described by *Jorge* (1896), again resembling *B. coli* in several respects and apparently still more closely related to *V. denitrificans Severin*, whose character and systematic position was discussed on page 59. *Jorge's* organism grew on agar mostly as a straight rod, in broth very much like *B. coli*, while on gelatin distinctly curved forms up to long spirals were predominant, some of them showing inflations at their ends. The pathogenic fluorescent vibrios, isolated from water by *Fuhrmann* (1905), may also be looked upon as indicative of relations connecting this group and that of *B. (Pseudomonas) fluorescens*.

Vibrio phosphorescens Dunbar gave, when cultivated by *Maassen* (1904) on agar containing 2–3 per cent lithium chloride, branched cells in very great numbers. As figure 84 on Plate VII *Maassen's* two photographs are reproduced (from original figs. XIII, 10 and XIV, 3). The forms shown are very similar to some drawn by *Dowdeswell* in his investigations upon cholera, mentioned above.

Several of the highly pleomorphous marine Hali- and Photobacteria described by *B. Fischer* (1894) should very probably take their place here. This is especially true concerning his *Halibacterium polymorphum*, which gave practically all kinds of cell forms, and all these in different sizes, in cultures not older than 2–3 days, and on most suitable substrates. There were recorded (l. c., p. 36): globules, short rods, comma and screw forms, irregular cells of large size (sometimes larger than yeast cells), pear-, hook-, and club-shaped forms, very long spindles with pointed ends, and irregularly curved threads. *Halibacterium pellucidum* and *Photobacterium tuberosum* exhibited also much of the characteristics of a vibrio. It is the same with *Photobacterium balticum* according to the description furnished by *Barnard* (1899).

Weibel (1887–1888) isolated several *Vibriones saprophiles*, another from the mucus of the nose, and one from the tongue, all of which exhibited pleomorphous tendencies. The "*Vibrio aus Nasenschleim*" is said to have furnished "eine Musterkarte abenteuerlicher Runen und Schnörkel." *Bajardi* (1903), who studied *Weibel's V. lingualis* anew, obtained among many other forms branched threads, which stained like *B. diphtheriae* when treated with *Neisser's* method. The organism, therefore, is declared to be a "Streptothrix." The picture given by *Bajardi* (as original fig. 1) is reproduced as figure 85 on Plate VIII. The growth on gelatin resembled Anthrax, and in broth Actinomyces-like clusters were found. Large yeast-like cells also became visible, and in older cultures the long threads were again replaced by short cells, often containing polar granules.

Bonhoff (1896) isolated from water, besides other vibrios and spirilla, a "Vibrio Rugula" with 18–20 polar flagella, which also gave branching and on the plate Anthrax-like colonies. It is, no doubt, quite different from the anaerobic cellulose-destroying organism, described by *Prazmowski* (1880) under the same name, and mentioned on page 68.

Probably the first example of branching among the spirilla was the frequently quoted *Spirillum endoparagogicum*, discovered by *Sorokin* (1887–1890). The formation of branches in this case was due, according to the author, to the germination of "spores" inclosed in the mother cell, wherein they appeared in various numbers. How far this statement can be accepted as correct will have to be discussed in Chapter II. The drawing given in the first paper (1887) is reproduced as figure 29 on Plate H.

Spirillum Undula grows, as *Kutscher* (1895 *b*) found out, in a small and in a large type. The latter one showed all intermediate stages leading over to straight rods, as did also other spirilla. Sometimes *Kutscher* saw that one end of a cell was curved, while the other one was entirely straightened. He also noticed with *Spirillum Undula*, as well as with *Sp. Serpens*, what seemed to him to be "ganz eigenartige Gebilde," viz., curved branches breaking forth from

the side or from the end of a spirillum. He does not want to decide whether or not this is true branching. *Sorokin's* papers were evidently unknown to him.

Doerr had the opportunity to see the same process with *Spirillum pyogenes Mezinescu*, taken from broth as well as from the pus, as is demonstrated by the photographs accompanying his paper, but there is nothing said about it in the text. The "new" *Spirillum bataviae* described by *Faber* (1912) gave again "hornartige Ausläufer," and again the author feels unable to reach a decision whether these are branches or not.

Reichenbach (1901) met very clear examples of triangular cells in six days old broth cultures of *Spirillum rubrum*. Some of his photographs (original figs. 6, 8, and 9) are reproduced as figures 86 and 87 on Plate VIII. They are very similar to those published by *Severin* from his *V. denitrificans* and by *Bordoni-Uffreduzzi* from his *Proteus hominis capsulatus* which have been mentioned on pp. 55 and 59, respectively. Other branched cells of *Spirillum rubrum*, reproduced as figure 30 on Plate H from a drawing of *Meirowsky* (1914 *b*) are interesting counterparts to *Spirillum endoparagogicum* and to *B. radicicola*. *Spirillum tyrogenum Denecke* gave *Meirowsky* analogous results.

Concerning the morphology of the spirochaets only comparatively few data are available at present, as the numerous pure cultures isolated by *Noguchi* (1911–1912) have not been closely studied in this direction.

According to *Sobernheim* (1907, p. 536) atypical forms of *Spirochaeta pallida* are not infrequent in syphilitic tissue. He says:

> Abgesehen von ungewöhnlich zarten Spirochaeten, sowie von sehr kurzen Spiralen mit verhältnismässig lockeren Windungen, sieht man zuweilen Exemplare der Spirochaete pallida, die schleifenförmig gewunden und verschlungen sind. * * * Involutionsformen in gestalt von kurzen, deformierten Fragmenten, gekörnten spirochaeten-ähnlichen Gebilden, aufgeknäuelten und verklumpten Spirochaeten sind mehrfach beschrieben worden.

Castellani (1905) found in yaws besides, or instead of the spirochaets, oval irregular bodies, usually 5–8 μ, but also smaller or much larger ones. Analogous results were reported for syphilis by *Krzysztalowicz* and *Siedlecki* (1908) and by *McDonagh* (1912), which will have to be considered more fully in Chapter II. *Niessen* (1898), too, got Blastomyces-like growth from his "syphilis bacillus" or "Syphilomyces." It is absolutely impossible, however, to separate clearly the correct findings from the probably more numerous incorrect ones, contained in all of this author's publications. Contaminations, especially those of diphtheroid bacilli, have obviously played a conspicuous rôle in these investigations.

Branched growth of *Spirochaeta pallida*, as well as of *Spirochaeta balanitidis*, *stomatitidis*, and *gallinarum*, has been recorded by *Meirowsky* (1914 *a* and *b*). Some photographs published in his second paper (original figs. XI, 46, 55, and 56) are reproduced as figure 88 on Plate VIII. They show an exquisitely mycelial growth of *Spirochaeta pallida*. The occurrence of coccoid bodies within the life cycles of these and of other spirochaets have been ascertained by different authors; but, being evidently reproductive organs, they are to be considered in Chapter II.

With *Spirochaeta Obermeieri* granular and rod-like forms have been seen by *Karwacki* (1912). Whether the pathogenic bacillus, isolated by *Afanassiew* (1899) from a recurrens case, is to be accepted as a type of growth of the recurrens spirochaete, remains to be seen. It is reported to have grown first as a fine motile rod (0.3×1.5 μ), which later passed over into curved threads of 5–14 μ length, sometimes with pointed ends and granular structure.

Inada, *Ido*, *Hoki*, *Kaneko* and *Ito* (1916) have published some very interesting pictures of the ring forms, buds and branches of their *Spirochaeta icterohaemorrhagica*, found by them to be the causative agent of Weil's disease. Two of their drawings (original figs. 69 and 70 on pl. 61) are reproduced as figure 31 on Plate H.

The *Vibrio* (*vel Spirochaeta*) *suis*, which by *Rüther* (1910), as well as by *King* and his coworkers (1913), has been connected with hog cholera, grows according to the first-named author in comma or in the typical spirochaete form, which, however, occasionally divides itself into fine rods, resembling *B. influenzae* or *septicaemiae*, or assumes a Streptococcus-like appearance.

A problem which remains to be solved despite a considerable amount of work already done in this direction, is the question, whether the fusiform bacilli, practically constantly to be found in symbiosis with spirochaets in healthy organs, as well as in pathogenic processes, like angina, pyorrhea, stomatitis, gingivitis, noma, are merely symbionts or parts of the life cycle of the spirochaets.

The bacillus found by *Babes* (1893) to be connected with scurvey, causing gingivitis and hemorrhages, which grew only on agar first used by streptococci, presented the typical fusiform appearance, but gave also curved threads "longer and thinner than cholera bacilli." In a later publication (1907) of the same author analogous results are reported about angina. *Silberschmidt* (1901) described a fusiform bacillus from an abscess, exhibiting all intermediate steps leading over to thin spirilla, of which, however, no pure cultures could be made. *Beitzke* (1904) gave a summary of the work done up to that time, which together with own experiments led him to the conclusion, that fusiform bacilli and spirochaets belong together genetically. On account of the occasional occurrence of branched threads he is inclined to place these organisms in the neighborhood of Bang's necrosis bacillus and the Actinomycetes.

Wechselmann and *Loewenthal* (1905) noticed that in syphilitic tissue very thin rods with pointed ends and metachromatic granules may accompany the spirochaets. From microscopic studies upon angina *Mackie* (1905) drew the conclusion that the fusiform bacillus, the spirillum, certain sickle-shaped and some ribbonlike bodies, found in such material, "will all turn out to be different stages in the life cycle of one parasite." The most important contributions thus far made in support of the view that bacilli and spirochaets belong together are those furnished by *Ruth Tunnicliff* (1906–1915). Pure cultures of fusiform bacilli isolated (1906) from material taken from the mouth proved to be "extremely pleomorphous." Spirochaets appeared only temporary in large numbers, and being not easily stained they may have often remained unobserved, although being actually present. During the first 24 hours delicate pointed rods of 3–10μ length, often resembling the barred type of diphtheria bacilli, became visible. Some plumper bacilli ($1.5\times4\mu$) with deeply stained rounded ends also were seen. The next day long filaments developed, and soon afterwards spirals appeared, some of them also containing dark bodies. They usually showed pointed ends, were Gram-negative like the bacilli, and sometimes clearly made up of a chain of rods. Work done with the anaerobic *Bac. rhinitis* (1913–1915) confirmed and extended the earlier findings. In another paper by *Rosenow* and *Tunnicliff* (1912) the same dimorphism was described in regard to an anaerobic organism isolated from a fatal case of pyemia. The spiral forms were frequent in the fluid of condensation of serum agar. Coccoid forms, too, were present which, however, obviously are to be classed as reproductive organs. *Proca* (1908) saw satisfactory development of *B. fusiformis*, when it was grown in symbiosis with *B. subtilis* or with streptococci. Such mixed cultures produced in broth many spirilla with large, often unequal undulations and thin ends. On agar and gelatin, especially at the surface, the typical straight forms prevailed, while in the depth of the agar curved forms also appeared. The "*Cladothrix stereotropa*," found by *Proca* and *Danila* (1910) in syphilitic products, is said to have produced besides diphtheroid forms, fusiform bacilli as well as spirilla.

Shmamine (1912) thinks that the "nadelförmigen" bacilli ocurrring in syphilitic material are a type of growth of *Spirochaeta pallida*. Both organisms produce the same colonies, are identical in staining qualities, and the transformation of the bacilli into spirochaets was observed. These "needle-shaped" bacilli are considered to be different from *B. fusiformis*. *Carpano* (1914) obtained analogous results in his investigations upon the "fuso-spirilläre Symbiose" in necrotic gangrenous affections; and pure cultures of the spindle bacilli, isolated by *Klimenko* (1914) from scarlatina, gave also spirilla after a few transfers. Again both organisms stained in the same manner, and salvarsan acted upon these bacilli as it does upon the spirochaets. *Ozaki* (1915) found that a spirochaete from the human mouth in pure culture always produced straight bacilli, which, however, were taken to be not identical with *B. fusiformis Vincent*. In their report upon a fatal case starting from pyorrhea, in which the fusiform bacillus was

isolated from the blood, *Larson* and *Barron* (1913) also took the standpoint that bacilli and spirochaets belong together.

On the other hand, the opinion has been repeatedly expressed that spirochaets and bacilli are two different organisms, because they could be separated and kept for some time in pure cultures without showing any change in their morphology. *Ellermann* (1904–1907), *Vincent* (1905), *Mühlens* and *Hartmann* (1906), *Veszprémi* (1907), *Doflein* (1909), *Peters* (1911), *Lehmann* and *Neumann* (1912, p. 578), *Krumwiede* and *Pratt* (1913), *Kendall* (1916, p. 531), for instance, share this view. However, taking under due consideration in the first place the experimental difficulties, so often encountered with in growing these organisms on artificial substrates, in the second place the abnormal conditions prevailing in artificial cultures, and in the third place the analogous outcome of the very numerous experiments carried on with other organisms, apparently though incorrectly proving their monomorphism and constancy, it seems best not to discard too rashly the positive findings mentioned above, and to wait for further thorough and unbiased research. It can, e. g., not be accepted as justified that *Arnheim* (1914) rejects *Tunnicliff's* results in their entirety, though he himself observed the transformation of spirochaets into rod-like forms ("stäbchenartige Gebilde"), as well as the prevalence of the latter forms in some types of syphilitic eruptions. And when he lightly discards the round bodies, which he also had the opportunity to see, as "Zerfallsprodukte," he merely adds another unfounded assumption to the multitude of similar assertions concerning "involution forms, degeneration," etc. It is quite characteristic that *Tunnicliff* in her first work upon this subject, done together with *Weaver* (1905) also did not find any connection between fusiform bacilli and spirochaets, but that her later more searching investigations led to the opposite standpoint.

One point which needs emphasizing in this connection is the necessity to distinguish more sharply between the different bacilli included in this group than has been often done so far. The papers published by *Lewkowicz* (1906), *Babes* (1907), *Veszprémi* (1907), *Costa* (1909), *Shmamine* (1912), *Larson* and *Barron* (1913), *Ozaki* (1915) and others, furnish valuable material in this direction. It is very probable that some of these incompletely studied so-called fusiform bacilli have nothing whatever to do with spirochaets, while in other cases the opposite will be true.

A peculiar organism with a creeping motion, isolated by *Miehe* (1913) from leaves of tropical plants, and described by him as *Bact. repens*, seems to be related to those members of the Fusiformis group, whose character exhibits protozoon-like traits (cf. *Babes*, 1907). As figure 32 on Plate H two of *Miehe's* drawings are reproduced (from original figs. 9 and 10 on Pl. II). The curved, branched, and swollen, so-called involution forms duplicate very closely the similar growth of the spirilla.

(e) HIGHER BACTERIA (TRICHOBACTERIA, MYCOBACTERIA).

As organisms are included among spirochaets and fusiform bacilli, which evidently act as links connecting bacteria and protozoa, so among the so-called higher bacteria the relations become more and more apparent, which lead over to the fungi on the one side, to the algae on the other.

Many of the details collected on the preceding pages amply support the statement made on pp. 21–23 that all bacteria studied more thoroughly exhibit traits which so far have been generally considered to be characteristic for Actinomyces and some closely related organisms. Special genera (Actinococcus, Actinobacter, Actinobacillus) have been proposed, and it is a fact always to be kept in mind that especially the large endospore-forming bacilli of the Anthrax-Subtilis-Mycoides type are easily induced to enter a development very much resembling that of a typical Actinomyces. Some of the pros and cons in regard to a transplantation of Actinomyces and its relatives among the fungi have been mentioned already (on pp. 21–23), and others will be discussed in Chapters II and III. As some of the Actinomycetes are known to enter temporarily a motile stage, while others have thus far always shown themselves to remain permanently immotile, one might feel induced to accept this difference as the dividing

line between those belonging to the bacteria and those belonging to the fungi. In many cases, however, presence or absence of motility can not even be used as a means to separate bacteria (like *B. coli, dysenteriae, mycoides, subtilis, fulvum,* and others) into different species. Therefore it would be at least premature to use this mark as a basis for separating those organisms, at present all grouped together as Actinomycetes, into bacteria and into fungi. Thorough investigations upon their complete life cycles are also in this case quite indispensable before any well-founded decision can be rendered.

The same holds true concerning Beggiatoa, Cladothrix, Crenothrix and related organisms, which repeatedly have been declared to belong to the algae, not to the bacteria. Again this may be the case, but much of what is known at present seems to indicate their bacterial nature. As will be shown in Chapters II and III, it is especially their modes of multiplication and reproduction which connects them more closely with the bacteria than has been thought before. In fact, as Actinomyces has been declared (by *Claypole,* 1913) to be an "ancestral type" for bacteria, as well as for fungi, so Crenothrix, Cladothrix, Beggiatoa and related forms may be looked upon as prototypes, showing clearly such reproductive processes as occur also with all bacteria, though they nearly always have been overlooked thus far. It will be much more useful, therefore, if also these organisms will be made the objects of further bacteriological investigations, than to exclude them prematurely on account of insufficient systematic reasons. The general character of an alga, of a fungus, or of a protozoon is rather different from that of a Beggiatoa, of an Actinomyces, or of a Spirochaeta. Certainly these organisms are also more or less different from the majority of the bacteria, but just as some of their characteristic traits can be found with true bacteria, too, it seems best to retain them in their present position as "higher bacteria."

The organism described by *Bang* under the name abortus bacillus grows in the body as a fine small rod similar to *B. erysipelatos suum.* That the latter species is related to the Actinomycetes, has been emphasized by *Rosenbach,* who established for it the genus Erysipelothrix (see p. 52). That the abortus bacillus should take its place among the Corynebacteria, in the neighborhood of glanders, diptheria and diphtheroid organisms, has been pointed out by *Preisz* (1903). The cells growing in the cultures are either short, coccoid, sometimes very similar to the double-pointed forms of *Streptococcus lanceolatus,* or they are longer, thin, irregularly stained like the barred type of *B. diphtheriae,* passing over into wedge-, spindle-, and club-shaped forms. Y and more complex branching was found to be not infrequent. The Gram staining is said to have always given negative results. Interesting relations connecting this species with *M. melitensis* have been mentioned on page 44.

The necrosis bacillus of *Bang* is also to be placed here as being identical with the so-called *Streptothrix cuniculi,* described by *Schmorl* (1891). Cocci, motile and immotile rods, threads, branching and the formation of drumstick-like cells have been recorded by this author. Two of his photographs are reproduced as figures 89 and 90 on Plate VIII (from original figs. 2 and 5 on Pl. VII). *W. Ernst* (1902) did not find any motile rods, but he gives many details concerning the formation of branched threads, large inflations, ball-, pear-, and bottle-shaped cells.

The Streptobacillus described by *Tizzoni* and *Angelis* (1913–1915) as causative agent of pellagra, grows at first as motile thin rods, which break up into typical, but gram-negative, streptococci. These pass over into gram-positive staphylococci, which eventually reproduce rods. The latter were often found interspersed within the streptococcus chains. These, too, show branching; and clusters ("Drusen") with granular center and clubs at the outside also have been seen. The colonies made up by the cocci were flat, white, glistening, and liquefied gelatin.

That the glanders bacillus may be easily induced to change its character was emphasized by *Th. Smith* as early as in 1890. Acid reaction of the substrate caused a yellow-orange growth, while alkaline reaction made it grayish. A great variety of "puzzling involution forms" was noticed by this author. *Semmer* (1895) reported that glanders, as well as tubercle bacilli, are much inclined to form under saprophytic conditions threads which often show inflations, clubs,

and branches. The short rods are declared to be a type of growth adapted to the environmental conditions within the body. *Marx* (1899) secured further information upon the pleomorphism of this organism. Figure 33 on Plate H is a reproduction of his figures 1–4.

Galli-Valerio (1899, 1900) confirmed and extended these findings by a close study of the development of the glanders bacillus on different substrates and in the hanging drop. Small and large rods, clubs, dumb-bell-shaped and drumstick-like cells, as well as branching, were observed. The drumsticks alone are declared to be "involution" forms, not the others. The short small rods were found to appear in old cultures, after the large branched threads had disappeared. More data and pictures have been furnished by *Conradi* (1900). Branches appeared in his cultures already on the second day; basis and apex of the threads could be easily discerned. The organism is declared to belong to the Hyphomycetes. Excellent photographs, clearly illustrating the wide pleomorphism of *B. mallei*, have been published by *Carpano* (1913) and are reproduced as figures 91–96 on Plate VIII. As was emphasized by this author all the various forms appeared on the same substrate (acid glycerin horse-meat agar), which fact will be of special importance for future investigations upon the life cycle of this organism.

Before the etiologic significance of the diphtheria bacillus was fully established, repeatedly coccoid forms have been made responsible for this disease. It may be readily admitted that the presence of true micro- and streptococci might have caused some erroneous conclusions. Nevertheless, as new and well-founded observations have shown that the diphtheria bacillus is able to appear in a distinctly coccoid shape, those older findings deserve once more some interest. When *Oertel* (1871) directed the attention to the "micrococci" as causative agents of diphtheria, he cautiously pointed out that the "purely botanical problem concerning their true nature and relationship" should not be touched by him. He only made use of that name in the general sense as was done by *Hallier*, and he mentioned already that not only round but also long forms became visible which even were seen to sprout forth from round cells. With less precaution *F. Cohn* (1872 b) created a distinct species *Micrococcus diphtheriticus*, which later was transferred by *Zopf* (1885, c p. 53) into the genus Streptococcus. *R. Koch* (1878) also emphasized "that in diphtheritic deposits large numbers of micrococci are present," and he thought that probably the same cocci were active in pyemia as in diphtheria. *Baumgarten* (1890, p. 353) says:

> Es ist kein stichhaltiger Grund vorhanden, dem Streptococcus pyogenes die Anerkennung als eines Erregers der Hals- und Rachen-Diphtherie zu verweigern.

Guenther (1906, p. 577) takes a similar standpoint.

The pleomorphism of the true diphtheria bacillus was first studied by *Zarniko* (1889). He observed club-shaped cells, three- to four-fold longer than the normal rods, segmentation of the original bacilli, and the separation of these segments, which assumed spherical and ovoid forms. All these "atypical" cells were declared to be "involution" forms, though they were well and uniformly stained. *E. Klein* (1890–94) refuted this assertion. Club-shaped, as well as budding and branching forms, which he was the first to observe, are said not to be involution form, because they are present in young cultures and at the outbreak of the disease. The same holds true, as was stated in the second paper (1894), with regard to the spherical forms. In his monograph upon the diphtheria bacillus *Escherich* (1894) expressed the opinion that the branched cells present in the diphtheritic membranes, as well as in other parts of the afflicted throat, should be classed as secondary infection caused by a "Cladothrix," and he was inclined to accept as erroneous diagnoses those findings where cocci alone had been seen. Typical is, according to his opinion, the small wedge-shaped rod with rounded ends ($0.3–0.5 \times 1.2–2\mu$), which may pass over into elongated and clubbed forms. Spindle-, dumb-bell-, pear-shaped, as well as curved cells, were also seen. Moreover, from old cultures, as well as from the animal test, very long irregularly curved threads were obtained, which exhibited various inflations, some of them assuming the shape of chains of giant cocci. Weakly stained rods are declared to simulate sometimes streptococci, the chro-

matic granules taking the stain much better than the surrounding sheath. Concerning the relations existing between true diphtheria and diphtheroid bacilli *Escherich* takes the standpoint that both are strictly different, although he admits, of course, that the diphtheria bacillus may lose its virulence entirely.

His mistake concerning the absence of branching was soon corrected by a short paper published by *Fraenkel* (1895), wherein it is pointed out that the method usually followed in making the smear nearly always destroys the branched forms, which, however, are produced at least by some strains quite regularly in fresh serum or egg cultures. *Bernheim* and *Folger* (1896) soon confirmed *Fraenkel's* observations, while *Kanthack* (1896) directed the attention of the German bacteriologists to the fact that analogous results had been previously obtained in England by *E. Klein* and by himself. *Zupnik* (1897) noticed that not only the cell form, but also the form of the colonies of the diphtheria bacillus can vary to a great extent. Some of his strains were found to be motile. In 3–4 weeks old broth cultures *Madsen* (1897) observed many small and large, regular and irregular globules, which looked like a contamination by cocci. But all intermediate stages leading over to the clubbed rods were visible, and plate cultures showed that the strains were pure diphtheria bacilli. More details concerning the branching of the diphtheria bacilli were furnished by *Kurth* (1898). The club-shaped form of the branches shown in his pictures makes an exact duplicate to the drawings of branched streptococci, published by *Babes* (1895) and reproduced as figure 3 on on Plate B. He thinks that such forms are restricted to the true diphtheria bacillus, and that they could be used, therefore, in differentiating from the pseudo-diphtheria group. Evidently he was unaware that *Babes* (1895) had already given the analogous pictures of diphtheroid organisms, reproduced on Plate J as figure 34. Very interesting is the observation of *Kurth* that in symbiosis with *Streptococcus lanceolatus* the diphtheria bacilli became so similar to them, that they hardly could be distinguished. *Meyerhof* (1898) once more discussed the great pleomorphism of the diphtheria bacillus, and confirmed that branching is very frequent on egg substrates. Very careful studies upon dividing and branching of the diphtheria bacilli have been made by *Hill* (1899, 1902), who for this purpose made use of his newly developed "hanging agar block" method. With young cultures he succeeded in observing directly the "snapping off" of oval side branches and their stretching out to normal rods.

It was by no means in accordance with the facts known at that time, and in part without logical foundation, too, that *Migula* (1900, Vol. II, p. 499) wrote concerning the diphtheria bacillus:

> Dass diese Verzweigungen . . . nichts weiter als Involutionserscheinungen sind, braucht wohl nicht erst besonders hervorgehoben zu werden . . . Überhaupt ist der Diphtheriebacillus sehr leicht zur Degeneration in morphologischer Hinsicht geneigt, und dies umso mehr, je besser er sich an die künstliche Kultur gewöhnt hat.

Weesbrook, *Wilson*, and *McDaniel* (1900) arranged the different forms shown by the diphtheria bacillus into seven types; each of them containing cells of granular, barred, and solid staining. Granular forms were found to predominate at the beginning of the disease. The resemblance to *Streptococcus lanceolatus* is very pronounced in types D and G. As *A. C. Abbott* remarked in the discussion following the reading of this paper, representatives of all seven types probably occur in every culture. Many of them, however, are according to his opinion "simply involution forms." Their appearance is greatly influenced by the hydrogen ion concentration of the substrate (*Bunker*, 1917). *Cache* (1901) reported upon another case of considerable persistency in branching in successive subcultures, and *Concetti* (1901) secured further information upon the reciprocal relation between virulence on the one side and club formation, branching, and luxuriance of growth on the other side. Under anaerobic conditions the Actinomyces-like forms could be reverted to the typical rod of high virulence. Additional data in this direction are to be found in a paper published by *Ohlmacher* (1902), some of which were accepted by the author as proof of the possibility of changing true diphtheria into pseudo-diphtheria bacilli. As was mentioned on p. 47, a puzzling "streptococcus" also was found, which in various directions came very close to the character of a member of the diphtheria group.

Beck (1903) thought that the club-shaped form should be considered to be the normal type of growth of the diphtheria bacillus; branching again was found to be frequent in young cultures. A picture of a 1-day-old growth on agar (l. c. p. 765, fig. 1) shows clearly small and large globular and oval forms. *Spirig* (1903) got typically Actinomyces-like growth from old diphtheria cultures: long thin threads dividing up into rods and cocci, forming a white powdery ("kreidig") layer on the surface. But at the same time he revoked an earlier statement of his (1899) concerning the development of branched threads. They were now declared to have been those of a contaminating "Streptothrix," just as had been assumed by *Escherich* (1894) in analogous cases (see above, p. 77). *Goodman* (1908) discussed fully the great morphological and physiological variability of the diphtheria, as well as of the pseudo-diphtheria, bacilli. He comes again to the conclusion that all be "but variants of a single species, *B. diphtheriae*, which constitutes the entire group." The facts secured by *Smirnow* (1908) concerning the growing of *B. diphtheriae* in coccoid form, when living together with streptocci and other bacteria, confirm the analogous findings of *Kurth* (1898), mentioned above. *Cappellani* (1910) encountered repeatedly in the beginning of the disease in fresh exudate highly virulent diphtheria bacilli showing good branching, which was reproduced in the transfers on different substrates. He supposes again, like *E. Klein* (1890), that the rods are merely adaptations to the parasitic life, while the actinomycotic growth is the normal development under saprophytic conditions.

In the course of diphtheria tests made in Hamburg, *J. Dale* (1910) repeatedly met with unusual miscroscopic pictures, as shown in figure 97 on Plate IX (reproduced from original fig. 6). This photograph makes an interesting counterpart to figure 91, coccoid forms of *B. mallei*. The secondary colonies, which developed from such coccoid growth. were again made up of typical diphtheria bacilli. Soon afterwards *Balfour* (1911 *d*) reported that in the tropics clinically true diphtheria cases frequently are caused by pure cultures of curious cocci, showing *Neisser's* granules and developing characteristic diphtheria colonies on Loeffler's serum, which, however, are composed exclusively by Gram-negative cocci. In subcultures on agar typical rods were found within 48 hours, while on serum the cocci remained constant. The photographs appended to the paper are quite similar to that of *J. Dale*.

A study of the diphtheria group (including pseudo-diphtheria bacilli) by the biometric method was made by *Morse* (1912). Six morphological types are described and correlated with cultural and biochemical characteristics (chromogenesis, acid production, virulence, toxin production and complement fixation). They are arranged in two main subgroups: (1) true diphtheria bacilli—(*a*) virulent, (*b*) avirulent; (2) diphtheroids, to which reference will have to be made below. *Berry* and *Banzhaf* (1912) were unable to confirm the results recorded by *Goodman* (1908) mentioned above. They explain them by assuming that Goodman had worked with a "mutating organism." Their own experiments show very wide and irregular variations in the production of acid, despite the title of the paper: "Nonvariability of Diphtheria Bacilli."

That, in fact, the variability of these organisms is by no means inferior to that of other bacilli has been fully demonstrated anew by *Baerthlein* (1913), by *Bernhardt* and *Paneth* (1913), and by *Schmitz* (1916). *Baerthlein* noticed many changes in 2–4 weeks old cultures, which seemed to him to be examples of true "mutation." Three types of colony and cell form were found to be regularly present. *Bernhardt* and *Paneth*, as well as *Schmitz*, conclude from their observations upon the morphological and physiological variability of the diphtheria bacillus in cultures and in the body, that true and pseudo-diphtheria bacilli are to be accepted as strains of one species. Secondary colonies were especially inclined to furnish aberrant forms. That the inoculation into the animal is very efficient in bringing about such changes, as was observed by these authors, has been confirmed by *Römer* (1914). *Park* and *Williams* (1914, p. 38) mention the fact that "many large, intensely staining forms with one to several apparent branches and many metachromatic granules" were usually present in 6–12 days old cultures, and that they were the only ones which showed active growth and division. The same authors also give (1. c., p. 294, fig. 119) an interesting picture of a strain which grew exclusively in the form of a large coccus. *Heinemann* (1917) found irregularities in toxine production connected with variations in growth and in microscopical appearance. Strains of low toxicity

gave thick yellowish films, which were composed of diplococci, resembling strepto-and meningococci. The great importance of this observation for the correct diagnosis of diphtheria is emphasized by the author, who evidently was not aware of the fact that he once more confirmed what had repeatedly been discovered by several independent workers. A very complete description of the wide pleomorphism of the diphtheria bacillus was published by *Bergstrand* (1918). The occurrence of various globular forms was also thoroughly studied in this case.

The relations existing between streptococci and pseudo-diphtheria bacilli were pointed out by *Babes* in 1895. As figure 3 on Plate B his drawings of branched streptococci, showing club formation, were reproduced. They make an interesting counterpart to his sketches of clubbed pseudo-diphtheria bacilli, reproduced as figure 34 on Plate J (from original fig. 3). How the bacilli may pass over into "streptococci," is also well discernible in these early drawings. *Escherich* (1894 p. 190-225) was the first to show that the diphtheroid organisms are not less pleomorphic than the true diphtheria bacilli. When *Seitz* (1896) isolated several streptococci from the mouth, he also got one strain which was considered to be an avirulent diphtheroid. Its colonies were entirely like those of the streptococci, its cells showed globular, triangular, rodlike, club-shaped, and many other irregular forms. The staining with Gram's method gave positive, as well as negative, results. Early observations upon branching of pseudo-diphtheria bacilli have been recorded by *Kanthack* (1896). A "Bacterium diphtheroides," isolated by *E. Klein* (1900) from the pus of a diseased udder, grew in serum mostly in globular or ovoid form, while only a few wedge-shaped rods indicated its true character. *Nakanishi* (1900 *c* and *d*) made a diphtheroid from the skin the object of very careful studies, because for some time he believed to have discovered the causative agent of variola. It started its growth as triangular coccus, later stretched out into short and long rods, which became beaded and eventually turned over into club-, dumb-bell-shaped or branched forms. These sometimes remained constant in successive transfers. In the animal test bright globular or oval bodies appeared, which in artificial substrates assumed again the bacillary form. Those shown in figure 98 on Plate IX (reproduced from original fig. 8) invite a comparison with the coccoid growth of diphtheria and glanders bacilli (figs. 96 and 91).

When discussing the question of virulence among pseudo-diphtheria bacilli *Hamilton* (1904) admitted that usually the differentiation from the true diphtheria bacillus is not too difficult. But he also noticed that some virulent pseudo-diphtheria bacilli may become so similar to true diphtheria bacilli, that they can only be distinguished by animal experiments. *Clark* (1910), on the other hand, is of the opinion that so-called virulent pseudo-diphtheria bacilli are true diphtheria bacilli of atypical morphology. *Bac. Hofmanni*, however, is declared to be a different species, not merely a variety of the Klebs-Loeffler bacillus, though, according to the author, both "doubtless" came from "common ancestors." *Kolmer* (1912) considers the Hofmann bacillus to be a "mutation" of the diphtheria bacillus, connected with it by many intermediate forms. Wesbrook's types were studied anew, and the sugar test accepted as of practical value, "when used in conjunction with tests for virulence." *Morse* (1912) added to *B. Hofmanni* and *xerosis* as two new types of diphtheroids the pink growing "*B. hoagii*" and the yellow "*B. flavidus*." As mentioned above, *Bernhardt* and *Paneth* (1914) concluded from their experiments, that true and pseudo-diphtheria bacilli are strains of one species. Likewise *Trautmann* and *Gaethgens* (1913) report to have succeeded in changing experimentally avirulent diphtheroids to fairly virulent typical diphtheria bacilli.

From cases of Hodgkin's disease *Lanford* (1914) isolated a pink, highly pleomorphous organism of doubtful etiological significance, which assumed various shapes and sizes, from a cocco-bacillus, 1–2μ, to a large raquet-shaped bacillus, 8–10μ in length. In older cultures rods of about the size of *B. Hofmanni* were predominant. Occasionally relatively enormous oval forms became visible. The most complete work upon the morphology and the life history of various Corynebacteria, especially of several strains causing malignous granulom (Hodgkin's disease), which has been done so far, is that of *E. de Negri* and *Mieremet* (1913) and *E. de Negri* (1916). Single-cell cultures were used for these investigations which, as was already pointed out in our first paper (*Löhnis* and *Smith*, 1916 *a*, p. 696), represent a very welcome confirmation

and extension of our own observations upon the life cycles of the bacteria. Some of *Negri's* photographs, published in her second paper, are reproduced as figures 99–101 on Plate IX (from original figs. 11, 12, 30, and 73), showing granular forms from whey agar, threads from serum, round cells and thin rods from serum, together with a yeast-like cell from granulom (magnification in all these cases × 560). The pathogenicity of the last-named cell form is especially noteworthy. That *Negri* erred in placing her organism among the Blastomycetes has been discussed before (*Löhnis* and *Smith* 1916, *a*, p. 697). It is not improbable that at least some of the so-called bottle bacilli from the skin, which are of a rather uncertain systematic standing (see p. 22), are analogous types of growth of common diphtheroids

The close relations existing between this group and the streptococci have been made the object of more thorough studies by *Walker* and *Adkinson* (1917) and by *Mellon* (1917). The organism, isolated by the first-named authors from sputum of patients with bronchial asthma, produced different types of colonies on plain and on dextrose agar. Some of them were very small, opalescent, looking like tiny dew drops; they contained streptococcus-like forms, Gram-positive, as well as Gram-negative, within the same chain. Under certain conditions they passed over into diphtheroid bacilli, while in other cases they remained fairly constant. Frequently a chain was made up of Gram-positive and Gram-negative cocci, oval forms, and true rod-shaped bacilli. The authors are convinced that "many of the streptococci found in sputum may be really diphtheroid organisms rather than true streptococci, and this may even apply to the hemolytic streptococci." Another type of colony was dirty white, raised in the center, and with undulate margin. It contained chiefly Gram-positive bacilli, but also Gram-negative bacilli, cocci and diplococci. Still another type was large, round, flat, thin, whitish and very tenaceous. In it usually Gram-positive cocci predominated, some of which were very large. *Mellon's* strain was isolated from the lung (pulmonary fibrosis). When grown in broth containing a few drops of human or rabbit serum, the bacilli of the barred type disintegrated, and their chromatine masses became diplococci, as shown in figure 35 on Plate J (reproduced from original fig. 2, p. 88), which later grouped themselves either as staphylo- or as streptococci. It was difficult to revert these cocci into the original barred rods, but this was done successfully on slightly acid, as well as on comparatively strongly alkaline, substrates. In the animal this organism also acted like a streptococcus of low virulence. *Mellon* mentions especially the relations connecting his strain with *Thiercelin's* Enterococcus. A glance over the foregoing pages, as well as over the references given on pages 46–48 in regard to the diphtheroid growth of various streptococci, will suffice to demonstrate in addition, that analogous relations between numerous members of both groups are indicated in many of the earlier publications. In the third part of *Mellon's* paper the name *B. enzymicus* was proposed for the subgroup related to the streptococci; it was found to be present everywhere in the body. Other diphtheroids displayed some proteus-like characteristics; they were motile and liquefied gelatine. *Eberson* (1918) believes that the diphtheroids should be separated into not less than nine groups, all of them having the character of true species. With regard to *B. enzymicus* it is assumed that the presence of coccoid forms is either due to a contamination, or they are, indeed, produced by the diphtheroid organism; in this case, however, the author does not want to have them classed as "true" cocci.

B. leprae was introduced into the literature by *G. A. Hansen* (1880–1882) and *A. Neisser* (1881) as a slender motile bacillus, forming round "spores." *Babes* (1883) saw frequently round swellings at the end of the rods, and in the tissue between the rods small round elements (0.5–1.5μ) in small groups or chains, which stained the same way as the rods. Another early but little known contribution was made by *Lutz* (1886), who noticed that after careful decolorization (with alcohol + nitric acid) of a strongly stained preparation (Gram's method was especially useful for this purpose) all bacilli presented themselves as chains of well stained cocci within weakly stained sheaths. Really homogeneous rods were never seen by him. Sometimes at the end of the rods, or separated from them, other larger round bodies became visible, either very darkly stained or not at all, or reacting like metachromatic granules. That some

of these were reproductive cells was discussed by the author and will be considered in Chapter II, while other still more interesting observations are to be reserved for Chapter III. Some of *Lutz's* drawings are reproduced as figure 36 on Plate J (from original figs. 7–11 on p. 81). He proposed to place the leprosy organism in a special genus Coccothrix, which also had to embrace the tubercle bacillus and related forms. *Bordoni-Uffreduzzi* (1888 *a*) noticed that homogeneous or granulated rods became visible in his preparations, according to the mode of staining employed. In addition to the round swellings at one end of the rods, he met also dumb-bell-shaped cells.

In 1897 *E. Levy* described for the first time an only slightly acid-resistant Actinomyces-like organism, related to *B. tuberculosis*, which was isolated from a case of leprosy. More details upon this organism were given by *Czaplewski* (1898). Young cultures contained homogeneous acid fast rods; in older material the granules only were stained within the decolorized bacilli. In broth thick round bodies were formed in the middle or at the end of the rods; clubs and branches became also visible, the latter especially in gelatin. The etiological significance of the organism was left in doubt. Similar diphtheroid strains were secured by *Teich* (1899) in five different cases, which grew either as thin rods, like in the tissue, or displayed the wide pleomorphism characteristic for this group.

Barranikow (1900–1902) was the first to state that the leprosy organism is characterized by a "complicated life cycle." Form, staining reaction, acid-resistance, and virulence were found to be different in the various phases of life. Washing with water was sometimes sufficient to take away all stain. *Kedrowski* (1901) confirmed that leprosy like other so-called acid-fast bacilli are by no means constantly acid-resistant, and he also confirmed the wide pleomorphism of this species. Cocci, rods of different shape and size, clubs and sometimes typically Actinomyces-like growth were observed. Young bacilli proved to be motile. The author states that like plague, glanders, diphtheria, and tubercle bacilli so also the leprosy organism passes through a complicated life cycle outside of the body, and that the branched forms are one of the stages of growth entered at this time. *Kedrowski* continued his investigations for a long time, and in a second paper (1910) he was able to furnish much additional proof concerning the pleomorphism, but also concerning the etiological significance of his organism. Figure 37 on Plate J (a reproduction of original fig. 37) demonstrates clearly the "Coccothrix-," as well as the Actinomyces-like, habit of growth.

The discoverer of the leprosy bacillus, *G. A. Hansen* (1903), however, was not inclined to accept any of these cultures as genuine leprosy organisms. He could not turn his mind from the strict monomorphism, in vogue at the time when he made his discovery (1879). Changes in form, acid-resistance, and especially the occurrence of branching were to him convincing proof of untrustworthy investigations. This anachronism was rectified a few years later by another paper on the same subject, published in the same "Handbuch," by *Babes* (1907 *a*).

The results of extensive investigations carried out in British India, published by *T. S. Williams* (1911), are in complete agreement with *Kedrowski's* work. The "*Streptothrix leproides,*" as it is called here, grows as bacillus or Streptothrix (i. e. Actinomyces) of changing acid-resistance. The excellent pictures accompanying the paper show also coccoid forms. In his "Études sur les Actinomycètes" *Galli-Valerio* (1912) gave some interesting drawings of clubbed and spindle-shaped cells of *Mycobact. leprae*, as taken from the tissue. Making use of single-cell cultures, *Reenstjerna* (1912) proved definitely that a culture of the leprosy organism, whose pathogenicity was established by experiments on monkeys, was able to grow temporarily as a not acid-resistant streptococcus. *Kritschewsky* and *Birger* (1912) made some serum tests, which indicated that *Kedrowski's* culture was the true *B. leprae*, while another culture from *Duval* did not react with these sera. A very thorough discussion of the whole subject is contained in two papers by *Wolbach* and *Honeij* (1914), who are of the opinion that in the different parts of the world apparently different varieties are acting as causative agents: (*a*) the diphtheroid, (*b*) the acid-fast pigmented, and (*c*) the acid-fast not pigmented groups. Their own culture once more exhibited an "extreme pleomorphism." In young cultures short coccoid, not acid-fast forms in pairs were prevalent, but acid-fast granules and segments were also al-

ways visible. In addition, not acid-fast slender rods with acid-fast granules (i. e. *Lutz's* "Coccothrix") and club-shaped cells, whose swollen ends were usually acid-fast, were present. Inoculation experiments and agglutination tests were considered not to be conclusive.

On the other side, the standpoint taken by *G. A. Hansen* was defended by *Duval* and his collaborators. In 1912 *Duval* and *Wellman* described a nonchromogenic, constantly acid-fast rod, morphologically resembling the diphtheria bacillus, which grew only on specially prepared substrates, and whose etiological significance seemed to be probable. The pleomorphism observed by other authors was contested. In 1913 *Duval* and *Harris* pointed out anew that the acid-fast character of their culture was "as constant as that of *B. tuberculosis*" (which they apparently assume to be constant) and that no streptothrical and filamentous stages became visible; only diphtheria-like "involution" forms were recorded. In 1914 *Duval* extended and confirmed these statements: All his cultures grew constantly as acid-fast rods. Those, however, which did not adhere to this "legitimate" course, were discarded as contaminations, though no proof was available to support this assumption (see the quotation given on p. 20). In addition, in 1915 *Harris* and *Wade* did not only demonstrate that diphtheroids are to be found everywhere on and in the body, in air, water, etc., and that those isolated by them were again entirely constant, they also did not hesitate to take these findings as a basis for the assertion that the opposite results, obtained by all other authors, were simply to be explained as caused by impure cultures. A fitting remark, made by *Bayon* (1915) in regard to such an assumption, was quoted on page 21. More recently *Duval's* standpoint has been made quite untenable by the work done by *Johnston* (1917), who declares himself wholly in accord with *Kedrowski* and *Bayon*. He states that the leprosy organism has two stages in its life history: a streptothrical not acid-fast form, and a bacillary acid-fast one.

The pleomorphism of *B. tuberculosis* was emphasized as early as in 1883 in two publications by *Klebs*. While *R. Koch* (1882) strongly insisted upon the constancy and the monomorphism of his bacillus, and the presence of these bacilli was declared by him to be the only valid proof of true tuberculosis, *Klebs* pointed out, that always, even in *Koch's* own cultures, coccoid forms were regularly to be found, some of which seemed to be motile. The bacilli are, according to his opinion, one type of growth of the tubercle organism, and their presence is declared to be undoubtedly of great diagnostic value. As causative agent, however, the cocci are considered to be of the same, or even of higher, importance. Observations published by *Babes* (1883) at the same time fully confirmed this view. Not infrequently no bacilli could be found in tuberculous tissue, but "grains bien colorés, ronds ou cubiques, se rapprochant de l'apparence des sarcines". These round bodies were, as in leprosy, 0.5–1.5μ in diameter; they were stained in the same manner as the rods. The bacilli were also seen to contain sometimes round inflations in the middle or at the end. In the same year (1883, p. 67) *Zopf* emphasized that, despite *Koch's* statement, the tubercle bacillus may assume the form of a coccus. The critique directed by *Flügge* (1884) against *Zopf* remains an interesting document of the manner in which the monomorphistic dogma was established and defended at that time. But at the same time *Biedert* and *Sigel* (1884) emphasized once more that in chronic cases the regular bacilli may be entirely replaced by granular rods and accumulations of "granules" not stained by aqueous aniline dyes, but stained by a modified Gram method.

In 1883 and 1884 *Malassez* and *Vignal* also published their important papers on "tuberculose zoogléique, forme ou espèce de tuberculose sans bacilles." Like *Klebs* and *Babes*, they often found during several transfers in the animal test only "masses zoogléiques de microcoques"; then the bacilli appeared, and later they disappeared again. In their first paper the authors state clearly: "Il existe une parenté entre nos zoogloées et les bacilles de Koch." In the second paper, however, they leave this point open to further research. Their drawings show, that the micrococci, which they observed, were sometimes considerably larger than the round bodies inside of the bacilli. Several authors have later assumed that this "tuberculose zoogléique" of *Malassez* and *Vignal* had been some kind of pseudo-tuberculosis, an assumption which is evidently not in accordance with the facts reported by the French bacteriologists, and which is likewise contradicted by the more recent observations of *Spengler*, *Much* and others

to be mentioned below, which fully confirm those older discoveries. After *Lutz* (1886) had noticed that the tubercle bacilli, when treated in the same manner as he did with the leprosy bacilli, also assumed the appearance of a "Coccothrix," *Klebs* (1887) modified somewhat his earlier standpoint; he now thought that the coccoid forms which he had seen, should be also declared as "Coccothrix." This explanation, however, is not in full agreement with those observations which revealed the presence of single, comparatively large, globular, acid-fast bodies in tuberculous tissue. Fig. 102 on Plate IX is a reproduction of a sketch published by *Cornil* and *Babes* (1890, Vol. II, p. 402, fig. 342) of a cut through the pia mater in tuberculous meningitis, showing such "grains ronds qui se colorent par le même procédé que les bâtonnets."

That the tubercle bacilli may pass over into branched forms was first ascertained by *Metchnikoff* (1888*a*) for the avian type. Cultures kept at 44° C. exhibited a great pleomorphism, as shown in figure 38 on Plate J (reproduced from original fig. 20 on Pl. V). That the branching is the result of budding is clearly visible in the picture, as is also the occasional separation of oval side branches (*s* and *n*–*n'*), i. e., the same process which was described later by *Hill* in regard to the diphtheria bacilli. It was emphasized by *Metchnikoff* that the branched forms should not be classed as "involution" forms. More data upon branching also of the human and bovine types of the tubercle bacillus have been contributed during the next years by *E. Klein* (1890–1894), *Mafucci* (1892), *Fr. Fischel* (1893), *Coppen-Jones* (1893–1895), *Bruns* (1895), *Semmer* (1895), *Kanthack* (1896), *Olsen* (1897), and *Marpmann* (1897). Most of these authors reached the conclusion that the bacilli are merely a type of growth of an organism which should be classed among the Actinomycetes or even among the higher fungi. (See p. 21.) Club-shaped cells were very frequently found by *Coppen-Jones* in sputis from far advanced cases. *Babes* and *Levaditi* (1897) were the first to produce experimentally typical Actinomyces-like clusters ("Drusen") with clubs in the animal tissue. Their results were soon confirmed by *Schulze* (1899) and by *Lubarsch* (1899).

Ferrán (1897*a*), on the other hand, reported that by successive adaptation of the tubercle bacilli to ordinary broth (without glycerine) he had been able to reduce their acid-fastness and to induce them to grow at 20° or even at 10° C. as motile coli-like rods, which, however, were still able to produce typical tuberculosis in guinea pigs, simultaneously reverting to the original type of growth. Temporary motility in young homogeneous cultures was also recorded by *Schumowski* (1898–1899), by *Courmont* and *Descos* (1902) and by *Hawthorn* (1903*a*).

Schürmayer (1898) encountered small and large nonacid-fast globular forms of the avian type, which reproduced typical rods. Some pictures presenting Streptococcus-like, but still acid-fast growth in scrophulous glands, which were published by *Arrigo* (1900), are reproduced as figures 103 and 104 on Plate IX (from original figs. 1*a* and 2*b*), where they make a sharp contrast to the richly ramified thread in figure 105, reproduced from a photograph made by *Migula* (1900, Vol. II, fig. 3, Pl. V), who had "no doubt" (though, of course, also no proof) that such abundant growth is "merely degenerate." *Dorset* (1901*a*) found another good example of budding and branching of the human type in a 6-weeks-old glycerine broth culture. The bovine type, when cultivated in the frog by *Herzog* (1903), changed its morphology to such an extent that, as the author says, it seemed to be very doubtful at first whether the forms observed were really merely transformations of the organism tested. *Wolbach* and *Ernst* (1903), too, found the morphological variability of the tubercle bacillus under different conditions and especially in rapidly growing cultures "most extensive," leading from small cocci up to long threads and large branched forms.

The greatest deviation from the "legitimate" form, which had been declared by *R. Koch* and his followers to be the decisive indication of true tuberculosis, was probably that described by *Schroen* (1904). According to this author the tubercle bacillus passes through three different developmental cycles whose complete description, though promised in this paper, apparently has not been published. The causative agent of phthisis is considered by *Schroen* to be an organism of peculiar standing and not to be connected with the tubercle bacillus, which is accepted as only causing tuberculosis, not phthisis. Description and pictures of this "new phthisiogenic microbe," as it is called, leave, however, not much doubt that they actually refer

to a type of growth of the tubercle bacillus, analogous to that produced by *B. radicicola* within the root nodules, but never on artificial substrates. As this will be discussed in Chapter III, the discoveries of *Schroen* will also better find their place there.

In a paper entitled "Polymorphisme du bacille de Koch dans les produits de l'expectoration phthisiques" *Piery* and *Mandoul* (1904) established the following four morphological types: "(1) les homogènes courts, (2) les homogènes longs, (3) les moniliformes courts, (4) les moniliformes longs." Like *Lutz*, these authors are of the opinion that the tubercle bacilli are made up of chains of well stainable granules, which are surrounded by sheaths of variable stainability. According to *Péju* and *Rajat* (1907) successive cultivation of the tubercle organism in broth containing up to 4 per cent potassium iodide proved to be very efficient in stimulating lateral budding and multiple branching, as well as the production of other aberrant nonacid-fast forms. Large inflations of 6–8 μ diameter and typical mycelial growth were also observed. Analogous results were secured by *Arloing* (1908) by keeping the cultures at 44.5–45.5° C, and under increased atmospheric pressure (2.5 atmospheres). *Miehe* (1908) made some observations upon branching of the tubercle bacillus in the hanging drop. The globular and ovoid bodies were again accepted by *Betegh* (1908) as the initial stage in the development of the tubercle bacillus. They were seen by him to produce very thin, straight, nonacid-fast rods, which increase in size, become acid-fast, and assume usually a somewhat curved shape. These rods, first homogeneous, later become granular, and finally disintegrate again into these round bodies. *Much* (1907–1909) made some new attempts to convince the German bacteriologists, that *Koch's* monomorphistic dogma was indeed not in accordance with the facts. Once more the infectious nature of the coccoid type of growth and the occurrence of tuberculosis without the "legitimate" tubercle bacilli were clearly demonstrated. The passing over of acid-fast into not acid-fast forms and the opposite process were also closely studied.

Probably thus far the most complete investigation upon the life cycle of *B. tuberculosis* has been made by *Maher* (1910–1915). The transformation of the typical rods into granular forms, the loss of acid-resistance, the passing over into filamentous, coccoid, and yeastlike cells, and the regeneration of not acid-fast, as well as of acid-fast, rods were carefully followed. Of special interest, however, are the discoveries made by this author in regard to the symplastic stage of the tubercle organism, which will be discussed in Chapter III. The coccoid, as well as the yeastlike, cells could again be cultivated as such, in the same manner as it was done, for instance, with the Corynebacteria by *E. de Negri*. Unfortunately, only rather short reports have been published by *Maher;* and several hypotheses incorporated in his papers (assuming, e.g., the tubercle bacilli to be the offspring of the acid-fast spores of *B. subtilis*, and meningococci, as well as pneumococci, to be the progeny of the tubercle bacilli) evidently have had the effect that his discoveries did not elicit adequate attention.

Much's work has been confirmed and extended by *Krylow* (1911), who noticed that in vitro, as well as in vivo, very young tubercle bacilli were not acid-fast and also Gram-negative, but could be easily stained with aqueous aniline dyes. The Gram-positive substance, i. e., the granular mass, is the next to be developed, while the acid-fast material appears later within the membrane. The pleomorphism again was found to be very conspicuous already in young cultures. Analogous results were recorded by *Klepzoff* (1912), who points out that these changes seem to indicate relations connecting the *B. tuberculosis* and the Pasteurella groups. From the latter he was able to get acid-fast growth, too. Several interesting drawings of branched threads and of clubbed forms of *Mycobact. tuberculosis* have been published by *Galli-Valerio* (1912); and more details concerning the variation in acid-resistance and cell morphology may be found in a paper by *Wherry* (1913 *a*) upon the "Chemical Conditions Influencing Acid-Proofness and Non-Acid-Proofness in a Saprophytic Culture of *B. tuberculosis*." Minute, as well as large, coccoid bodies, short and long, thick and thin, straight and curved rods, which were or were not acid-resistant, were all seen to occur in an old culture originating from *R. Koch's* laboratory.

The pleomorphism of the pseudo-tubercle bacilli is very similar to that of the genuine tubercle bacillus. *Preisz* (1894) published some interesting pictures of a strain isolated from

sheep, reproduced as figures 106 and 107 on Plate IX (from original figures III–V on Plate IX, all × 1,000), showing their diphtheroid growth, as well as a Streptococcus-like development, which practically duplicates that found by *Arrigo* with *B. tuberculosis* (fig. 103, Pl. IX). The pseudo-tubercle bacillus isolated by *Korn* (1899), from butter, showed in the cultures, as well as in the animal test, traits characteristic of the tubercle bacillus on the one side, of *B. coli* on the other. The "Coccothrix" form dominated in old agar and serum cultures. Branched, club-shaped and spermatozoid cells were also seen. Motility in young cultures was noticed by *Moëller* (1899) with his "Grass bacillus II." *E. Klein* (1899) did not see active motility, but also his culture showed two polar flagella when stained with *Ermengem's* method. Typically actinoymyceslike clusters ("Drusen") in the animal test were obtained by *Lubarsch* (1899) with pseudo-tubercle as with genuine tubercle bacilli. The organism described by *Bongert* (1901) under the name *Corynethrix pseudo-tuberculosis murium* exhibited an analogous behavior, and the author points out that this club formation is a normal mode of growth, not a sign of degeneration. *Moëller's* grass and hay bacilli were also seen by *Abbott* and *Gildersleeve* (1902) to grow in the tissues very much like Actinomyces and *Bac. tuberculosis*. All pseudo-tubercle bacilli tested by *Courmont* and *Descos* (1902) proved to be actively motile, like *B. tuberculosis*, in young liquid, homogeneous cultures. The partially acid-proof "Streptothrix," isolated by *Schabad* (1904) from a case of pseudo-tuberculosis, produced neither clubs, nor clusters, but it showed very clearly true branching. A close relationship to the true tubercle organism was noticed by *Sanfelice* (1905) when he studied another "Streptothrix," causing pseudo-tuberculosis.

Mycobacterium hyalinum and related species, whose peculiar physiological activity as benzine, petrol and paraffin destroyers has been investigated by *Söhngen* (1913), appeared in many respects very much like Actinomyces. On the other hand, however, they also resembled *B. radicicola*, growing in the same type of colonies and in the form of Y-shaped rods.

A fairly complete description of the morphology of Actinomyces in man was published by *J. Israël* as early as in 1878 in a paper discussing for the first time human actinomycosis. He enumerates as elements building up the clusters found in the pus: (1) thin threads; (2) granules of various size, some small like typical cocci, others larger, very bright, globular or oval; (3) peculiar pear- or club-shaped bodies of very variable size and form, apparently dividing longitudinally. Sometimes the granules alone were present in the tissues. All intermediate stages connecting threads and clubs were seen. Formation of buds was noticed, too. One of *J. Israël's* drawings (orig. fig. 4 on Pl. II) has been reproduced as figure 108 on Plate IX. The swellings visible therein are of special interest, because very similar formations have been later seen by *Metchnikoff* (1888 *b*) with his *Pasteuria ramosa*. When *O. Israël* (1884) first succeeded in cultivating *Actinomyces hominis* on serum, he also obtained the characteristic club formation in vitro for the first time. The causative agent of the "farcin de boeuf" was named by its discoverer *Nocard* (1888) "bacille de farcin;" but already this first description leaves no doubt that this organism is a true Actinomyces. A special paper upon "The Morphology of Actinomyces," by *McFadyean* (1889), adds to the cocci, rods, threads and clubs already known, large circular bodies, which are believed to be related to the clubs. The latter were found to react differently when treated with Gram's method; and the cocci, too, were seen to be able to grow differently, viz., they either multiplied as such (in very young colonies) simulating strepto- and staphylococci, or they stretched themselves to rods and threads (in older colonies).

The very complete studies by *Bostroem* (1890) upon human actinomycosis brought much confirmation especially to the first findings of *J. Israël*. The clubs were seen to divide longitudinally as well as transversely, within the threads cocci, short and long rods were observed, and with young rods motility was ascertained. The pathogenic organism, isolated by *Eppinger* (1890) from a case of pseudo-tuberculosis and named by its discoverer *Cladothrix asteroides*, undoubtedly is also a true Actinomyces, though no clubs became visible. *Eppinger's* erroneous view concerning the mode of branching has been mentioned on p. 21. Coccoid as well as rod-like cells were found to be actively motile in young broth cultures. In old cultures the rods produced within the threads were seen to slip out, leaving the empty sheath behind. The thermophilic "Cladothrix," met by *Kedzior* (1896) in water, showed also true branching

and the characteristic powdery layer, so frequently produced by the Actinomycetes on solid substrates. Coccoid forms and young rods again exhibited motility. The same behavior was observed by *Rullmann* (1896, 1898 *a*) with his *Cladothrix odorifera* (i. e. *Actinomyces odorifer*), as well as with a yellow "Streptothrix," isolated from saliva. Another *Actinomyces* obtained by *Schürmayer* (1900) from tuberculous tissue, and described by him as "*Oospora* (*Streptothrix*) *proteus*" on account of its pleomorphism, grew temporarily in the form of motile cocci or motile rods. The cocci in this case again were able to multiply as such for some time, when kept at a low temperature. They then appeared like streptococci, but the tendency to produce branched compounds was much more pronounced than with genuine streptococci.

Feistmantel (1902) studied more closely the variable acid-fastness of "*Streptothrix farcinica*" and of other Actinomycetes. His results are very similar to those quoted above for *B. tuberculosis*. Full descriptions of the life history of *Eppinger's* organism, now correctly called *Actinomyces asteroides*, were published by *MacCallum* (1902) and by *Nakayama* (1906). According to *Doepke* (1902) different species may cause actinomycosis in man, some of them are aerob, some anaerob, clubs may be formed or may be absent, the coccoid forms may grow as such, or they may revert to rods and threads. Much variation in the formation of clubs and in their staining reaction has been also recorded by *Hollandt* (1906) and by *Loele* (1908). Gram staining and acid-fastness may even vary with the different parts of branched clubs. Occasionally threads were found by the first-named author up to 6μ broad, producing different kinds of gonidia, which fact was accepted as indicating a closer relationship between Actinomyces and Crenothrix. A detailed description of an *Actinomyces variabilis sp. n.* was given by *Th. Cohn* (1913). With the pleomorphism of the cells the formation of different colonies, was also studied in this case. Comparative tests of numerous Actinomycetes, contributing some additional details in regard to their pleomorphous character, have also been made by *Claypole* (1913) and by *Kràinsky* (1914).

Among the so-called thread- or trichobacteria the old genus Leptothrix has been frequently mentioned as a prominent example of bacterial pleomorphism. However, the early observations of *Robin* (1871) and his contemporaries undoubtedly can not be accepted as sufficient proof in this respect, and several so-called Leptothrix species probably have been nothing else than a thread-like growth of other bacilli, principally of lactobacilli and of aerobic, as well as of anaerobic, spore-forming bacilli. *Leptothrix gigantea*, as described by *Miller* (1883), appears very similar to Crenothrix. The very different size of the threads, the slipping out of coccoid and of rod-like cells from the sheath, and their growing up, are the same in both cases. *Zopf* (1883) added to cocci, rods and threads, spiral forms as another type of growth of Leptothrix. With *Leptothrix buccalis* he ascertained later (1885) that the coccoid forms again may multiply as such for some time, before returning to the thread-like growth. The Leptothrix cultivated by *Dobrzyniecki* (1897) from the mouth, gave colonies similar to those of *B. anthracis*. One of the photographs accompanying the paper seems also to show some branching. *Vincentini* (1893), too, studied a so-called *Leptothrix racemosa*, which, however, has been clearly a complex mixture of different organisms. *Beust* (1907) thought that *Bacillus buccalis maximus*, *Leptothrix maxima*, *Lept. innominata* and *Lept. racemosa* should be considered to represent merely stages in the life history of one organism.

Cladothrix dichotoma is characterized, according to *F. Cohn* (1875, p. 185), by its tendency to exhibit "false" branching only. But repeatedly the genus name has been erroneously used for naming species which belonged to the genus Actinomyces. *Zopf* (1881–1882) described as different types of growth of *Cladothrix dichotoma:* Cocci, rods, spirilla and threads; but his findings, though based on continuous miscroscopic observations, were strongly contested by *Winogradsky* (1888, p. 111). The results recorded by *Billet* (1890), however, are again in good agreement with those of *Zopf*, while *Büsgen* (1894) took his stand on *Winogradsky's* side. Spiral forms were not seen by him; small and large globular cells were discarded as "merely involution forms;" rods and threads alone were accepted as normal types of growth. *Migula* (1900, p. 39) published an interesting drawing (original fig. 45), which is reproduced as figure 39 on Plate K, presenting Cladothrix (*a–f*), as well as Actinomyces (*g–i*). Form and flagella-

tion of the motile cells are like those of *Azotobacter agile*, as seen by *Beijerinck* (1901 *b*). But while the picture given of "false" branching (*a*) is evidently a duplicate of that made by *Cohn*, the other figure (*e*), showing branched material grown on agar, seems to indicate, as far as can be seen from it, that also true branching may occur with this organism. The position of many of the branches, as sketched, is obviously not compatible with the assumption of "false" branching. If the growth which *Migula* had on his agar has really been that of Cladothrix it would demonstrate that under such conditions the resemblance between Cladothrix and Actinomyces (*e* and *h*) is indeed much greater than is generally believed. To *Migula* not only the cocci, but also the rods in old agar cultures are "merely involution forms." The frequently contested observations by *Zopf*, including those relating to the liberation of spirals with polar flagella from the Cladothrix threads, have been more recently confirmed by *Ellis* (1912) in his "Investigations into the Life History of *Cladothrix dichotoma* (Cohn)." He comes to the conclusion that Cladothrix is related on the one side to Crenothrix and Clonothrix, on the other to Pseudomonas and Spirillum.

Cocci, rods, threads, and spiral forms were also found by *Zopf* (1881–1883) with Beggiatoa. All short forms exhibited temporary motility. The coccoid cells either propagated as such, or they reverted into rods. *Engler* (1882) confirmed these results, but they were again utterly discredited by *Winogradsky* (1888). That, however, *Winogradsky's* statements can not be accepted as well founded, has been discussed (on p. 38). The answer given by *Zopf* (1895) deserves full attention, especially because new results are recorded therein, which confirm those obtained before. The findings of *Billet* (1890) were also in complete agreement with those of *Zopf*.

Crenothrix, too, can form, according to *Zopf* (1879), cocci, rods, and threads, and the cocci may either multiply as such or grow up to threads. Crenothrix is said to be unable to produce branches, *Schorler* (1904), however, who otherwise confirmed *Zopf's* results, also encountered a very similar, but branching, organism, which was made the type of the new genus Clonothrix. Only future experiments with pure cultures will make it possible to decide, whether this separation has been correct, or whether branching is equally common within this group as it is with all other bacteria.

3. CONCLUSIONS.

In regard to the occurrence of different cell forms within the various groups of bacteria the following conclusions can be drawn from the facts discussed on pp. 7–88:

(1) The monomorphistic theory of *F. Cohn*, *R. Koch*, and their followers, still accepted by many bacteriologists as being correct, is irreconcilable with numerous facts, which prove conclusively that all bacteria are pleomorphic. All well studied species—like *Micr. candicans*, *gonorrhoeae*, and *meningitidis; Strept. pyogenes*, *lanceolatus*, and *lactis; Bact. pestis*, *pneumoniae*, *radicicola*, *coli*, *acidophilum*, *bifidum*, *proteus*, *erysipelatos suum*, *pyocyaneum*, and *fluorescens; Bac. anthracis*, *subtilis*, *Azotobacter*, *Amylobacter*, and *Chauvoei; V. cholerae*, *Spirochaeta pallida; Corynebact. mallei* and *diphtheriae; Mycobact. leprae* and *tuberculosis*—have shown themselves to be able to grow in various, round, straight and curved, small and large, regular and irregular, cell forms. Budding, branching, and apical growth are common with all bacteria.

(2) That it was possible to uphold the monomorphistic theory for a considerable length of time, despite its erroneousness, is due to the following reasons:

(*a*) Differences in the cell form and in the appearance of the colonies have been usually accepted as a priori evidence of difference in species; and, therefore, most of the cultures exhibiting such differences, have been rejected as being contaminated.

(*b*) Genuine bacteria have often been laid aside as being no bacteria at all, because they showed budding, branching, or other peculiarities, which, according to the monomorphistic theory, should not occur with bacteria.

(*c*) In nearly all cases where undoubtedly pure cultures of true bacteria have exhibited various cell forms, only one of them has been accepted by the monomorphistic theory as "typical" or "legitimate," while the others were discarded, without adequate test, as being "atypical," "degenerate," or "involution forms."

(*d*) The cultural methods, as developed by the founders of the monomorphistic doctrine, make it often possible to keep a culture fairly constant for a considerable length of time, and to secure a continuous development of only one type of cells. Natural variations, as well as the different phases in the life cycles of the bacteria, are not easily noticeable under these conditions; but wherever they have been observed, the characteristic changes in cell morphology caused by them usually were again mistaken as growth of a "contaminating" organism or as some uninteresting "involution" form.

(3) In practically all cases where the so-called involution forms have been properly studied, it has been found that it was a mistake to classify them as such. This has been fully proved especially with *Micr. gonorrhoeae* and *meningitidis; Strept. pyogenes* and *lanceolatus; Bact. pestis, pneumoniae, radicicola, aceti, coli, typhi, proteus*, and *pyocyaneum; Bac. anthracis, mycoides, Azotobacter, Chauvoei*, and *tetani; V. cholerae, Spirochaeta pallida; Corynebact. mallei*, and *diphtheriae, Mycobact. leprae*, and *tuberculosis*. The endospores alone exhibit all marks of real involution. Many of the so-called involution forms, however, are most frequent when the bacterial development is at its height, part of them can be propagated as such, and later they are again replaced by the smaller cells of simpler morphology. The latter forms are generally best adapted to parasitic growth, though in the body, too, branching and otherwise "atypical" development is by no means absent.

(4) How far the alterations in morphological as well as in physiological behavior are due to variation and mutation among the bacteria can not be decided at present, because only insufficient information, or none at all, is available concerning the regular changes occurring in the different phases in the life cycles of the bacteria.

(5) The life cycles of probably all bacteria are composed of several subcycles exhibiting wide morphological and physiological differences. To secure all data pertaining to the life history of a species is much more difficult than to describe a bacterium in the ordinary manner. Long-continued investigations, made under different conditions, and controlled by a sufficient number of parallel tests, are indispensable in this case. Uniform cultural conditions and frequent transfers, made in regular intervals, tend to keep one type of growth constant; while successive transfers, made repeatedly during several weeks from and to various substrates, will always reveal more or less completely the pleomorphic character of every bacteria species. The best starting point for such experiments seems to be the symplastic stage, to be discussed in Chapter III.

(6) It is a grave, though often repeated, logical mistake to believe that the acknowledgment of the pleomorphism of the bacteria be equivalent to a negation of the existence and constancy of bacterial species. Just as all studies upon the pleomorphism of the fungi, algæ, and protozoa did not minimize, but have increased the accuracy in distinguishing between the various genera and species, so also systematic bacteriology will win considerably by every thorough investigation upon the life cycles of the different species. It is to be expected, and already clearly indicated by numerous well-confirmed results, that the old monomorphistic form genera and form species of *F. Cohn, R. Koch*, and of their followers will have to be thoroughly revised; and many of the so-called species, often described in the most superficial manner, will have to be canceled entirely as being merely fragments of the life cycles of other species. Only those species can be accepted as natural ones whose life history is fairly well known, and a correct systematic arrangement of the bacteria is not possible except upon such a natural basis.

(7) As far as can be concluded from the data available at the present time, it is probable that an increased knowledge of the life history of the bacteria will not lead to any change in the general position of the bacteria within the system. Their budding, branching, and apical growth may be considered as presenting additional evidence of their being related to the fungi, but it would not be justified to incorporate all bacteria on account of these characters among the fungi themselves, though this has been recommended by different authors. Other facts, especially with regard to the various modes of reproduction, undoubtedly strengthen the relations existing between bacteria and lower algæ, as well as between bacteria and protozoa. Many parallelisms are noticeable in the life histories of all these organisms; all of them are more or less pleomorphous.

II. REPRODUCTIVE ORGANS.

(GONIDIA. REGENERATIVE BODIES. SPORES. MICROCYSTS.)

1. GENERAL DISCUSSION.

In our first preliminary report (*Löhnis* and *Smith*, 1916 *a*, p. 700) we said concerning the reproductive organs:

All bacteria multiply not only by fission but also by the formation of "gonidia"; these usually become first regenerative bodies, or occasionally exospores. Sometimes the gonidia grow directly to full-sized cells.

The gonidia are either liberated by partial or complete dissolution of the cell wall, or they develop while still united with their mother cell. In the latter case the cell wall either remains intact or it is pierced by the growing gonidia, which become either buds or branches.

Some of the gonidia are filterable. They also produce new bacteria either directly or after having entered the symplastic stage.

The transformation of spore-free into spore-forming bacteria seems to be dependent on the conditions acting upon the symplasm and regenerative bodies.

The data collected on the foregoing pages will have shown that our observations concerning the pleomorphism exhibited by all bacteria in their vegetative stage, though at variance with the predominant monomorphistic doctrine, are amply confirmed by results obtained by many investigators, who in most cases have worked quite independently. In relation to the different modes and organs of reproduction of the bacteria the situation is very similar. If only the numerous findings to be quoted on the following pages would have met with adequate consideration, and if they had been brought into proper correlation, the doctrine still adhered to in most textbooks of bacteriology, that the endospores are the only special organs of reproduction of the bacteria, probably would never have been established.

As was said on p. 7, it is not always possible to reach a definite decision as to the vegetative or the reproductive character of certain cell forms described in the literature. Therefore, it will be necessary to refer occasionally back to one or the other item mentioned in Chapter I.

Before the special discussion of the character, the formation, and the development of the different reproductive organs is taken up, a brief historical resumé upon the discovery of the various modes of bacterial reproduction may be given first. In the second place the differentiation between reproductive organs and other cell products and artefacts must be considered. A few remarks upon some special problems (filterable vira, cell inclusions, aphanozoa, chlamydozoa, ultra-microorganisms, and heterogenesis), which become more easily accessible from our newly-won standpoint, will be added at the end.

(*a*) THE DISCOVERY OF THE DIFFERENT MODES OF REPRODUCTION.

When *E. Chr. Ehrenberg* in 1838 described the "infusoria" as "complete organisms," the genus Monas was reported as being able to produce "eggs," which in the case of *Monas Okenii* were seen to be liberated by the cells. With the small species of Monas, like *Monas termo*, as well as with spirilla and spirochaets, no analogous details could be made out. In the genus Vibrio, however, such granules were observed, as was also the case with the comparatively large Ophidomonas. In Gallionella a special organ, built up by four or more globoid bodies, was discovered, which the author considered as some kind of "ovarium."

Perty in 1852 was able to furnish much more information. Speaking upon protozoa, he says (p. 66 and 67):

Ich glaube nach zahlreichen Untersuchungen die Überzeugung hegen zu dürfen, dass eine gewisse Klasse von Bläschen und Körperchen, welche man in den Wimperinfusorien entstehen sieht, zur Fortpflanzung dienende, den Sporen vergleichbare Keime seien, für welche der Name Blastien (*τὸ βλάστειον*, Keim, Trieb) vorgeschlagen wird.

Die Fortpflanzung geschähe hiernach nicht durch gewöhnliche Substanzteilchen, wie *Dujardin*, noch Eier, wie *Ehrenberg* annimmt, sondern durch eigentümliche, im Innern der Tierchen entstehende, allmählich zahlreicher werdende Körperchen.

Concerning the Phytozoidia the following statement was made (p. 76):

Bei ihnen kommen auch die beiden Fortpflanzungsarten durch Teilung und durch Blastien vor; freilich ist man manchmal zweifelhaft, ob man Blastien oder nur den durch fortgesetzte Teilung in zahlreiche Parzellen zerfallenen Inhalt des mütterlichen Geschöpfes vor sich hat.

When discussing the monads (p. 83) the blastia are identified with *Ehrenberg's* "eggs"; the Vibrionida, too, are declared to grow up (p. 104):

. . . aus Anfängen, welche verschwindend klein sind.

The great difficulties arising from the minute size of these blastia and of the newly developed organisms are repeatedly pointed out, as for instance in the following sentence (p. 67):

Diese Kleinheit verhindert meist ihre Wahrnehmung, wenn sie zerstreut ausser dem Infusorienkörper vorkommen; aus gleichem Grunde kann man auch die Unterschiede der Anfänge vieler mikroskopischer Wesen nicht genau wahrnehmen.

Perty has been credited with the discovery of the bacterial endospores, and his drawings of "*Sporonema gracile,*" reproduced as figure 40 on Plate K (from original fig. XV, 26), prove that his observations have been very accurate in this respect. But evidently it has been overlooked so far that he also gave admirable pictures of the formation and development of what we now call gonidia. His drawings of spirilla, reproduced as figure 42 on Plate L (from original figs. XV, 28, 29B, and 31), deserve our full attention. The formation of the gonidia within the organisms and the upgrowth of the normal spirilla from minute beginnings are illustrated as clearly as in only very few pictures published in the modern literature. Concerning the large globular bodies, visible at some of the spirilla, *Perty* says (p. 132):

Brachte man ein Tröpfchen (of the culture) in einen Tropfen Brunnenwasser auf die Objectplatte, so bildete alsbald ein Teil der Spirillen durch Gerinnung Kugeln an sich, mit denen sie sich anormal bewegten, manche noch leicht, andere mühsam.

That is, a description of the so-called plasmoptysis has been given in this early work, more accurate than much of what has been written more recently upon this subject.

About the small and large "spores," i. e., micro- and macro-gonidia, of Gallionella ferruginea *Perty* made the following remark (p. 215):

Die kleinsten Körnchen zeigen oft Molecularbewegung; grössere bewegen sich wie Monaden scheinbar willkürlich. Sollen sie zu Fäden erwachsen, so bildet sich zuerst eine Hülle um sie, dann teilt sich der Inhalt und die Hülle verlängert sich.

Notwithstanding many inaccuracies to be found in *Ch. Robin's* "Histoire des végétaux parasites" (1853), the following references concerning his *Leptothrix buccalis* seem worth being quoted:

On peut quelquefois observer dans leur intérieur de très petits granules ronds, placés de distance en distance p. 347).

These round bodies were thought to slip out of the rods, to make part of the "granulations moléculaires" floating in the saliva, and eventually to develop to new threads (p. 351).

That *Hallier* (1865 *a*) and *Lüders* (1866) have dwelled upon the same subject has been also of no avail, though *Hallier* was right when he reported that the "granules" not always reproduce new threads immediately, but may for some time multiply as such, or may develop into larger round bodies, i. e., regenerative bodies. His favorite hypothesis, however, misled him to see "Penicillium spores" in them, which, of course, were also present in his very impure cultures, as were yeasts and all kinds of molds. To *Hallier* (1866–1896) all these various fungi were the result of the upgrowth of the bacteria and their granules, first called by him "micrococci" and later "plastids."

Karsten (1869) seems to have been the first author who used the term "micro-gonidia" for the small bodies, called blastia by *Perty*. Apparently he was influenced by the idea which he shared with *Hallier*, that bacteria and their "seed" were the offspring of vegetative and reproductive fungus cells; for the latter he used the term "Pilzgonidien."

Burdon-Sanderson (1871) saw "spheroids" (probably spores) elongate to rods, but he assumed also that bacteria might develop from "ultra-microscopic" bodies, not visible in

homogenous liquids. *Oertel* (1871) reports that in his diphtheria investigations he not only found cocci and rods, but also "Zellchen mit sprossendem Keimschlauch," which, according to his drawing, have been very similar to those observed by *Rindfleisch* (1872) and reproduced as figure 41 on Plate K (from original fig. 1 on Pl. XVIII). That these cells were not germinating spores has been made clear by Rindfleisch's statement that the "punctiform" bodies were actively motile, probably by one flagellum. He observed also for the first time that micrococci sometimes do not divide regularly, but increase in size, forming giant cocci, whose rôle will be discussed later.

When *F. Cohn* (1870) gave the complete description of *Crenothrix polyspora*, the formation of its motile "micro- and macro-gonidia" was also pictured. In figure 43 on Plate L two of his drawings (original figs. 11 and 13) are reproduced, one showing "ein Sporangium in der Mitte bandförmig verbreitert," the other a lateral club, filled with finely granulated protoplasm, considered by *Cohn* to have a spore-like character. To the same author (*Cohn*, 1872 *b*) we also owe the first fairly accurate investigation upon the bacterial spores, which was supplemented (1876) by *R. Koch's* study upon the spores of *B. anthracis*. As the bacterial gonidia are to many modern authors "merely fat," it is not uninteresting that *Koch* thought the spores were made up—

. . . aus einem stark lichtbrechendem Tröpfchen, vielleicht einem Öl, welches von einer dünnen Protoplasmaschicht eingehüllt ist. Letztere ist die eigentliche entwicklungsfähige Zellsubstanz, während ersteres vielleicht einen bei der Keimung zu verbrauchenden Reservestoff bildet.

Much more important, however, is the fact that the very first photographs ever made of bacteria show in an excellent manner gonidia and regenerative bodies, i. e., those reproductive organs of the bacteria which, at the present time, are practically unknown to most bacteriologists. One of the pictures made by *R. Koch* (1877, original fig. 4 on Pl. XV) has been reproduced as figure 109 on Plate X. It shows, according to *Koch* (l. c., p. 423), "Bacillen mit mehreren seitlichen Sporen," and it is stated, in addition:

Die Sporen . . . sind dicker als der Bacterienkörper und treten kugelartig aus diesem hervor.

The bacilli concerned are said to be related to *Bact. termo*, i. e., *Bact. fluorescens*.[1] Figure 110 is a reproduction of one of our own photographs (1916 *a*, fig. 40) showing formation of gonidia and regenerative bodies by *B. fluorescens*. *Koch's* picture was made with 500-, ours with 1,000-fold magnification; otherwise both are very much alike, and it is, indeed, surprising that this old observation neither has been followed up by *R. Koch* or by one of his pupils, nor has met with adequate attention elsewhere in the bacteriological literature. Another photograph by *R. Koch* (1877, fig. 5 on Pl. XVI), reproduced as figure 111 on Plate X, demonstrates the analogous stage in the development of *B. anthracis* (× 700). In this case, however, nothing has been said in the text concerning these round lateral and terminal buds and free round bodies, clearly visible in the picture. Again a comparison with a more recent photograph may be helpful. Figure 112 on Plate X is a reproduction from a picture made by *Günther* (1906, fig. 29, smear from the spleen of a mouse, × 1000), which presents the same type of gonidia and regenerative body, and also an interesting side branch above the latter; but again all is passed without any remark by the author.

Billroth (1874) was, like *Perty*, of the opinion that besides spores ("Dauersporen") small coccoid bodies are playing an important rôle in the multiplication of the bacteria. He states (on p. 16)—

dass die zuerst in einer bacterienfreien Flüssigkeit sich bildenden Bakterien aus feinem und feinstem Coccos entstehen.

Concerning the formation and development of this "Coccos," we are told (pp. 21, 22):

Eine weit häufigere und deutlicher zu verfolgende Umwandlung des Bakterienkörpers ist die zu kleinen runden Kügelchen, zu blassem Coccos.

Der auf diese Weise in den Bacterien entstehende blasse Coccos vermehrt sich zuweilen gleich nach seiner Entstehung.

[1] Some authors, like *Hauser* (1885) and *Pfeiffer* (1888, p. 590) have been of the opinion that the old *Bact. termo* should be identified with *B. proteus*; *Beijerinck* (1897, p. 40) related it to *Bact. punctatum*, while *Macé* (1897, p. 913), *E. F. Smith* (1905, p. 170), and *Lehmann* and *Neumann* (1912, p. 411, footnote) define it as *Bact. fluorescens*. That this view is correct is evidenced by a remark made by *F. Cohn* (1872 *b*, p. 197) upon the green pigment produced by *B. termo*, and by a comparison of *R. Koch's* and our own photographs (figs. 109 and 110 on Pl. X).

Two of *Billroth's* drawings (original figs. 36 and 42), reproduced as figures 44 and 45 on Plate L, present several interesting details. Formation, multiplication, liberation, as well as upgrowth of the gonidia within the mother cell, are well discernible. The big inflations with their granules, usually discarded by later authors as "merely involution forms," make interesting counterparts to *Cohn's* Crenothrix "sporangium," shown in figure 43. It is especially noteworthy that the cells visible in figure 45, which are shedding their granules, were obtained from whey kept at 40–45 C., i. e., under conditions leading to an accumulation of lactobacilli, and just these organisms have furnished more recently excellent examples for this little known mode of reproduction. *Robin's* mixed species *Leptothrix buccalis*, mentioned above, probably also included some lactobacilli. *Billroth's* drawings should be further compared with those made by *E. Chr. Hansen* (1879) of acetic acid bacteria, which were reproduced as figure 15 on Plate E. The similarity of the reproductive organs produced by both groups of bacteria will be discussed on another page.

Bacterium putridinis, described by *Davaine* (1876, p. 23) as the cause of "une pourriture et ulcerations sèches" in plants, exhibited a very similar behavior. It is said to have presented itself in three different forms: "(1) en corpuscules amorphes, infiniment petits et innombrables, constituant un tourbillon mouvant dont la plupart des individues se perdent aux limites de la vision; (2) en filaments minces, courts, droits . . . atteignant au plus 0.005 mm. de longeur, . . . (3) en filaments generalement plus long . . ." And *Davaine* adds:

> Il est remarquable que les corpuscules les plus petits qui échappent presque à notre vue aient une vitalité supérieure à celles des bactéries bien développées. Ce sont sans doute . . . des germes.

The assumption that these germs might have been spores, on account of their "vitalité supérieure," would collide with the other fact mentioned before, viz., that "un tourbillon mouvant" was noticeable. That the resistance of the gonidia may be distinctly superior to that of the vegetative cells will be shown later.

In 1877 some good descriptions of the formation of gonidia by Cladothrix and Crenothrix were published by *Cienkowski*. He pointed out that it is often difficult to distinguish between gonidia and ordinary cell inclusions ("gewöhnliche Inhaltskörper"), and that the reproductive character of the former can be only ascertained by studying their further behavior and development. *Letzerich* (1878) saw that in blood taken from typhoid cases, isolated cocci grew up to large spheroids, called "Plasmakugeln," and that later new bacteria were formed within each of them. In 1878 *Ewart* recorded several equally interesting findings, secured by continuous observations of hanging drop preparations. With *Bact. termo* (1878 *a*) he found like *R. Koch* that bright, extremely small, almost spherical "spores" "escaped" from the cells, but he found in addition, that they were able to reproduce new rods. Not always, however, a direct upgrowth was observed; sometimes these "spores" first divided themselves into four "sporules," which multiplied as such for some time, but then gave again a new growth of rods. Analogous results were secured with Anthrax (*Ewart* 1878 *b*). Also in this case the "spores" either reproduced the bacilli directly, or at first "sporules" were formed, which grew as such for some time, before reassuming their regular function. That these so-called spores were no true endospores is proved, except by this behavior, by their not being heat resistant like genuine spores, according to *Ewart*, and by their taking the stain very easily, as was found out by *E. Klein*, who in 1883 made the same observations. The drawings made by the last-named author, which were reproduced as figure 21 on Pl. F, leave no doubt that these "spores" have been what we now call regenerative bodies and microcysts, which partially acted as gonidangia. *Perty's* discoveries upon the reproduction of spirilla have been confirmed by *Geddes* and *Ewart* (1878). Again the "spores" were seen to "escape" at the end or at the side of the cells. They were of unequal size, multiplied either as such, or grew up to new spirilla, and sometimes they were seen to be inclosed within larger spheres. Their multiplication took place by fission as well as by budding, inside as well as outside of the parent cells.

In the course of his investigations upon Actinomyces, *J. Israël* (1878) discovered that the "bright spores," formed in a lateral or in a terminal position by the threads, may multiply for some time as such before reproducing new rods and threads, and that the clubs, which

developed at the end of the threads, may either break up and liberate their granular content, or may produce "blasse Körnchenhaufen" by fission or by budding.

Van Tieghem (1879 *a* and *b*) studied carefully formation and germination of so-called spores of *Spirillum amyliferum*, of a vibrio, and of a spirochaete found in oysters. Unfortunately, their resistance against drying and heating has not been examined. In accordance with results obtained by *Heydenreich*, *Guttmann* (1880) ascertained that also Spirochaeta Obermeieri produces "spores," which occurred singly or in pairs, were actively motile, but could not be seen to grow up to new spiral forms. Similar motile "granules" were noticed by the last-named author in the blood of patients afflicted with pneumonia crouposa, scarlatina, typhus abdominalis, typhus exanthematicus, diphtheria, and erysipelas. Special attention was paid to their differentiation from other blood granules. More data relating to Spirochaeta Obermeieri were furnished by *Albrecht* (1881), who found nothing but granules in the blood during the intermittent stage, while during the attack all forms, from granules up to full grown spirochaets, became visible. He called the motile granules germs ("Keime").

Formation, multiplication and germination of the gonidia produced by the large trichobacteria (Crenothrix, Cladothrix, Leptothrix, Beggiatoa) have become well known by the studies made by *Zopf* (1879–1885). Figure 47 on Plate M is a reproduction of his drawings of Crenothrix Kühniana (1883, original fig. 6), figure 48 one of Beggiatoa alba (1883, original fig. 27).

Engler (1882) confirmed *Zopf's* findings and added a new form, *Phragmidiothrix multiseptata*. The picture he made from it has been reproduced as figure 46 on Plate L (from original fig. 24). It is of special interest because of the small branches, apparently produced by gonidia germinating within the sheath. However, no final evidence could be secured in this respect.

Unfortunately, the results obtained with these comparatively large organisms have not been used as a help for testing the smaller bacteria along similar lines. The trichobacteria were either declared not to be bacteria at all, or they were removed to a special position as "higher" bacteria (see p. 22). But all recent, as well as many of the earlier, observations prove conclusively that formation and development of the gonidia are very much alike with all—"higher" and "lower"—bacteria.

Another opportunity to become acquainted with gonidia and regenerative bodies was given to *R. Koch* (1881) when he made the two photographs reproduced as figures 113 and 114 on Plate X, showing anthrax and oedema bacilli in the tissue accompanied by globular forms. However, again, as in 1877, no attention whatever was paid to these forms, which fact is especially surprising, because at that time *Koch's* standpoint concerning the etiological significance of the anthrax bacilli was strongly contested by *Fokker* (1881–82), who pointed out that in numerous cases no bacilli but only small coccoid bodies had been found, and that the latter probably were produced by the former and reproduced them in their turn. More evidence was furnished in this direction by *Archangelski* (1883), *Roloff* (1883), and *Toussaint*. According to a communication made by the last-named author to *Magnin* (1884, p. 150), he noticed, like *Ewart* and *E. Klein*, that the anthrax bacillus is able to produce smaller and larger spherical or elliptical "sporangia," especially when kept in blood at 37–40° C. Three to six "spores" were seen to escape from each "sporangium," and a new development of rods from these "spores" was also directly observed by *Toussaint* in *Ranvier's* chamber.

In regard to the bacillus of symptomatic anthrax *Ehlers* (1884) came to similar conclusions; he says:

> Der Rauschbrandpilz bildet zwei getrennte Entwicklungscyklen, welche entweder in der Sporen- oder in der Coccen-Gonidienbildung ihren Abschluss finden.

These "cocco-gonidia" were also found to be able to reproduce typical symptomatic anthrax in the animal.

However, all these findings were discarded by the *R. Koch* school of bacteriologists. *Loeffler* (1887, p. 171) declared that *Fokker*, *Archangelski*, *Roloff*, et al. had been "wrong without exception," though he does not furnish any evidence supporting his statement. The absurd dictum made by *Fraenkel* in regard to the "unnecessary" and "illegitimate" nature of the coccoid reproductive organs of *B. anthracis* was quoted on p. 27. *Ehler's* results were dis-

credited by *Kitt* (1887), but later confirmed by *Grassberger* and *Schattenfroh* (1907). The interesting manner in which *Hibler* (1908) tried to get rid of the embarrassing presence of the large round forms (regenerative bodies or gonidangia) of *B. Chauvoei* has been mentioned on p. 67. Figures 115 and 116 on Plate X are reproductions of two others of his protographs (original figs. 17 and 18, Pl. VIII, ×2,000), which demonstrate clearly that with this species it is not so easily possible to overlook these "illegitimate" formations, as *R. Koch* and his followers could do with *B. anthracis* and the smaller bacteria. The convenient "explanation," that they are "merely inflations" or "simply involution forms," has, of course, proved helpful here as in many similar cases.

On the other hand, *R. Koch* (1882–1884 *a*) and several of his pupils did not hesitate to ascribe "spores" to tubercle, typhoid, and other bacilli, usually on account of no other reason than that these bacilli sometimes show inclusions, which are not stained by aqueous dyes, and that their resistance against drying may be sometimes rather high. *Koch* declared that the tubercle bacilli produce spores "like the anthrax bacilli," though he usually saw 4–6 unstained inclusions in each tubercle bacillus. And he also asserted that occasionally these not stainable "spores" alone were present within the tissue:

> Ihre Anwesenheit verrät sich nach dem Verschwinden der Bacillen nur durch die infectiösen Eigenschaften der käsigen Substanz, in welche sie eingebettet sind.

He also noticed that in some preparations only stained granules became visible instead of the bacilli, but there was no doubt to him that these were "granules of plasma cells." However, *Klebs* (1883 *a* and *b*), *Babes* (1883), *Malassez* and *Vignal* (1883–1884), *Biedert* and *Sigel* (1884), *Artigalas* (1885), *E. Klein* (1885), *Amrusch* (1886), and *Lutz* (1886) furnished soon a large amount of evidence that these stainable granules may be, and often are, the true offspring of the bacilli, and that they are able to reproduce the long forms.

The typhoid "spores" observed by *Eberth* (1880) and *Gaffky* (1884) have been refuted by *Buchner* (1888) and by *Pfuhl* (1888). Similar claims made by *Hueppe* (1884) concerning *B. acidi lactici* and *B. cyanogenes* were retracted by his pupil *Epstein* (1890). What *A. Neisser* (1881) and *G. A. Hansen* (1882) declared to be lepra "spores" have been undoubtedly regenerative bodies, as is to be seen especially from the description given by *Neisser*. The results of the leprosy studies of *Babes* (1883), *Lutz* (1886), and *Bordoni-Uffreduzzi* (1888 *a*) fully confirm this conclusion.

The florid hypotheses, developed by *Béchamp* (1883) in his book on "Microzymas" in relation to the bacteria and their various reproductive organs, have been distinctly unfavorable to further studies upon these problems; and the usage established by *Zopf* (1883) to take the term "cocci" as practically equivalent to "gonidia," has also caused considerable misunderstanding. *Hueppe* (1886, pp. 109, 125) blamed *Zopf* for this incorrect denomination; not every globular or ovoid body should be called coccus, and this name should never be used for reproductive organs. But *Hueppe* also emphasizes on the other hand (l. c., p. 133) that globular bodies which are able to multiply as such should be called cocci, not gonidia. So again *Zopf* would have been correct, because all gonidia undoubtedly can multiply as such by fission, as well as by budding, and often do so before reproducing the larger cells.

In his "Traité de Botanique" *Van Tieghem* (1884, p. 1105) introduced the name "cyst" as designating those resting cells, which later have been also called "arthrospores." He defines them as follows:

> Les kystes ne sont que des cellules ordinaires . . . qui grandissent, changent de couleur, épaissent leur membrane et passent enfin à l'état de la vie latente. À la germination, le corps protoplasmique du kyste, revêtu de la couche interne de la membrane, reprend sa couleur primitive, se cloisonne dans la même direction que lorsqu'il faisait partie de filament, déchive la couche externe cutinisée de la membrane et s'allonge au dehors.

The exact meaning of the term "arthrospore," introduced into bacteriology by *DeBary* (1884), has been given neither by him nor by *Hueppe* (1886), who made it popular. The latter author only points out that arthrospores are always of globular form and do not multiply as such. That he also recommended to include the gonidia among the arthrospores (l. c., p. 128) was an evident mistake.

Arthrospores were especially attributed by *Hueppe* (1885) to the cholera bacilli. His drawings, reproduced as figure 49 on Plate M (from original fig. 2), leave no doubt that he saw those reproductive organs, which we now call regenerative bodies. Germination by stretching was repeatedly observed; in one case formation, as well as germination, of this organ was continuously studied with the same cell. Increased resistance of these bodies, when dried, was also noticed. *Kitasato* (1889) was unable to confirm *Hueppe's* findings, and this negative result has been often quoted in the textbooks (e. g., by *Pfeiffer* 1896, p. 536; *Heim*, 1906, p. 187; *Lehmann* and *Neumann*, 1912, p. 517) as being full proof of the inaccuracy of *Hueppe's* work; but it has not been quoted, on the other hand, that there are recorded many more positive results, all confirming and extending *Hueppe's* discovery. *Babes* (1889) saw that terminal round bodies are produced by the cholera vibrio, which after separation grew up to new bacilli; within long spirilla he found several of such round bodies. Their higher resistance against drying was carefully tested by *Finkler* and *Prior* (1885), as well as by *Firtsch* (1888), with *V. proteus*, by *Weibel* (1888) with *V. lingualis* and *saprophiles*, and by *Esmarch* (1887) with his *Spirillum rubrum*, where the granules, as their author says, "are arranged like the peas in an opened pod." *Sorokin* (1887–1890) called these bodies "spores," though they did not stand the heating, but he saw them germinate while still within the parent cell, which process led to those interesting branched forms reproduced in figure 29 on Plate H, and induced him to call his organism *Spirillum endoparagogicum*.

Development of new cells from the gonidia, still inclosed in the old cell, has also been described and drawn by *Künstler* (1884) for his *Bacterioidomonas sporifera*. Nearly 20 years later the same occurrence was studied by *Chutton* and *Pérard* (1913). Their drawing, reproduced as figure 50 on Plate M (from original fig. on p. 1233), leaves no doubt that their *Metabacterium polyspora* is identical with *Künstler's* organism, whose existence was evidently unknown to them. Like *Künstler* they call the 1–8 new rods which were seen to develop from "masses chromatiques," "spores," obviously an erroneous interpretation.

Analogous endogenous upgrowth of the gonidia was discovered by *Finkler* and *Prior* (1884–1885) with their vibrio. They either saw the motile "spores" coming out of the mother cells and developing outside into new vibrios, or the "spores" remained and grew inside of the old cells, which increased in size and often assumed a club-shaped appearance. Later these "nurses" (Ammen), as the authors call them, broke up and set the new bacilli free. *Ferrán* (1885) described large round or mulberry-like bodies of the cholera vibrio, which grew up from the granules contained in the thread-like cells, and which either send out thin threads becoming new spirilla or produced new spirilla inside of their cell walls, which later dissolved. The Spanish author indicates in addition that similar modes of reproduction probably occur with cocci and bacilli, too, and he mentions a Dr. *Colvée* in Valencia who observed similar things with the tubercle bacillus. In another paper by *Künstler* (1885) "De la position systématique des bactériacées" the following important statements have been made concerning spore forming bacilli and spirilla:

> D'après certaines découvertes récentes il semblerait que ces formes se transforment souvent en vésicules claïres, de dimensions considérables rélativement à leur taille primitive. Dans ces vésicules se produisent une foule de spores, analogues à des microcoques, qui sont mises en liberté par la déhiscence des parois.
>
> Les spores des Spirilles se divisent au sein de leur enveloppe et finissent par acquérir alors la faculté de se mouvoir. Ce n'est qu'ultérieurement que les sporules deviennent libres et germent.

In the same paper a spirochaete-like organism has been described under the name *Proteromonas Regnardi*, which was placed between bacteria and flagellates, and which was found to produce an inflation at or near the middle of the body, from which small "buds" were seen to separate, which became motile and grew up to new individual cells of "Proteromonas."

The picture reproduced as figure 122 on Plate X from *Artigalas'* "Microbes pathogènes" (1885, original fig. 1 on Pl. 5) shows the giant cells formed by Pneumococcus, which the author calls "spores," producing and liberating "sporules." *Maddox* (1885) published at the same time a similar drawing of inflated, club-shaped cells of *Bacterium lactis* (i. e., *Streptococcus lactis*), which let out their deeply staining granular content, and which were accepted by the author as "sporangia," not as "degenerate" cells.

Evidently without knowledge of the work done in France, in England, and in Spain, *Schroen* (1886–1891) in Italy found out that the tubercle bacillus may produce globular "spores," which eventually increase in size and produce internally several "daughter spores," which later leave the cyst ("Kapsel") singly or in chains, forming again new granulated bacilli. With numerous other species (*B. anthracis*, *Megaterium*, *V. cholerae*, etc.) he secured analogous results. The content of the large inflated cells, the "involution forms" of the German authors, was seen to transform itself into small coccoid and rod-like bodies, which later were liberated. In a footnote to an abstract of *Schroen's* first paper, *Baumgarten* in his "Jahresbericht" (1886) strongly doubts the accuracy of this work and mentions as foremost reason for this that neither *R. Koch* nor he himself had ever noticed such modes of reproduction.

Klebs (1887, p. 76) was of the opinion that in many cases the deeply staining granules ("chromatophilen Körner") visible in the cells, which he named "microsomes," may serve as starting points for new bacterial development. *Hauser* (1885) noticed that the so-called involution forms of his *Proteus vulgaris*, whose interesting photograph is reproduced as figure 120 on Plate X (from original fig. 16 on Pl. X) often contained one or more small, dark granules, or, more frequently, a globular, bright body, whose nature remained problematical to the author. All these large, globular, pear- or dumb-bell shaped forms were actively motile, reproduced quickly (within 12 hours) luxurious colonies, could be made constant in their characteristic appearance, and proved to be fairly resistant against drying, i. e., they exhibited in no way any sign of "involution," but presented themselves as an interesting connecting link between rudimentary gonidangia and sporogeneous cells. The lateral bud attached to the long rod at the right side of the picture and the many small forms apparently growing up from the gonidal stage are equally noteworthy.

The organism described by *Bordoni-Uffreduzzi* (1888 *b*) under the name *Proteus hominis capsulatus*, which, however, undoubtedly is to be placed in the neighborhood of *B. pneumoniae*, produced within the body rods and large numbers of gonidia, as may be seen from the liver cut, reproduced as figure 123 on Plate X (from original fig. 6 on Pl. VIII); in the cultures also large globules were found, which reproduced rods, and many other irregular forms, mentioned already on page 55.

Of special interest is a report made by *A. Neisser* (1888) upon "spore" formation of *B. xerosis*. The bodies concerned, for which the special treatment, known as *Neisser's* spore-staining method, had been developed, are those granules or disks in the so-called barred type of the diphtheria group, which are now called gonidia, while *Neisser* used this term for the whole, club-like structure. The most important findings were these:

> Jedes einzelne Teilglied wächst wieder zu einem neuen Bacillus aus. Die Wachstumsrichtung dieser Teilchen steht aber senkrecht auf derjenigen, in welcher sich der einzelne Bacillus zu der keulenförmigen . . . Kette ausbildete.

This mode of development leads to the parallel arrangement of short rods of uniform length, so characteristic for this group. Bacilli containing 3 or 4 granules, "welche als erste Anfänge der Bacillen ganz kurze Ansatzstücke zeigen," were also present. And it was further emphasized that these "spores" are produced in greatest numbers when the development reaches its maximum, not when it comes to its end, as with *B. anthracis*.

All these observations are in good agreement with some of our recent findings concerning the development of the gonidia of *B. azotobacter* and of other species. Still more complete, however, is the coincidence of facts incorporated by *Tomaschek* (1888) in the drawings of his large *B. muralis*, reproduced as figure 51 on Plate N (from original fig. on p. 183), and those secured in our Azotobacter studies. In fact, every detail visible in this picture could be accepted as representing some stage in the development of *B. azotobacter*. The large ovals surrounded by concentric slimy layers, the formation of the small globular gonidia, their liberation, as well as their upgrowth inside of the mother cell, are all as with Azotobacter. *Hansgirg* (1889) vigorously maintained against *Tomaschek* that this so-called *B. muralis* be no bacillus at all, but a colorless alga. That again is exactly what has been asserted by several authors in

regard to the large cells of Azotobacter, though our more recent findings leave no doubt that they are merely a type of growth in the life cycle of spore-forming bacilli of the Subtilis-Mesentericus group.

Another interesting picture of the formation of gonidia within a bacillus has been published by *W. Miller* (1889, p. 54), when he described what he wrongly called *Jodococcus vaginatus*. A glance at figure 52 on Plate N (reproduced from original fig. 15) shows that it makes a good counterpart to some of the older drawings made by *Billroth* (see fig. 44 on Pl. L) and by others of the trichobacteria, and that *Baumgartner* (1909) was perfectly right when he removed this organism as *Bacterium iogenum* to its proper place.

What *Beijerinck* (1888), *Frank* (1890), and *Prazmowski* (1890) described as liberation of "swarming bodies" ("Schwärmer") by *B. radicicola* is, at least partially, to be classed among the early observations upon bacterial gonidia. The last-named author compared them to small bright globular spores ("Sporenkügelchen"); *Atkinson* (1893) called them zoospores.

Dowdeswell's investigations (1889–1890) upon the cholera organism brought much confirmation to those of *E. Klein*, *Ferrán*, and *Schroen*. "Sporangia" producing "sporules," rods, and threads splitting up into granules, and the regeneration of normal forms from these sporules were once more studied continuously with the living material. The drawing of a stained preparate of cholera, published by *Cornil* and *Babes* (1890, original fig. 275) and reproduced as figure 124 on Plate X, may be compared with *Hueppe's* sketches, reproduced as figure 49 on Plate M. An analogous picture of the first-named authors, showing gonidia and regenerative bodies of the tubercle bacillus, was reproduced as figure 102 on Plate IX.

MacFadyean (1889) noticed similar large globular bodies with Actinomyces and thought they were related to the clubs, while the smaller "cocci" were declared by him to be the "seed" for new development in the animal. *Bostroem* (1890) called the bright, darkly staining, pearlike granules which he found in and outside of the Actinomyces threads "spores." Within the clubs he also observed such granulated threads, which were seen later to disintegrate, liberating the "spores." That they may cause budding and branching was found out by *Eppinger* (1890), who noticed that the granule visible in the thread at first develops a small "wart," which then grows out into a branch, just as had been seen by *Sorokin* with his *Spirillum endoparagogicum*. The interesting forms of "*Streptothrix cuniculi*" photographed by *Schmorl* (1891) were reproduced as figures 89 and 90 on Plate VIII. The granules within the threads, but also their liberation are well discernible, especially their coming out of one of the inflations visible in figure 90; lateral buds and the beginning of branching are equally conspicuous. *Mafucci* (1892) recorded similar findings with the avian type of *B. tuberculosis*, and *Fr. Fischel* (1893) reported concerning the human type of this organism:

> In manchen der klöppelartigen Verdickungen sieht man beiläufig in der Mitte derselben äusserst kleine, hellglänzende, runde oder ovale, an sehr verkleinerte Milzbrandsporen erinnernde Gebilde.

Marpmann (1893) found in sweepings from the street round spore-like germs of the tubercle bacillus, which gave him normal cultures after having been kept for one hour in the steam. *Coppen-Jones* (1895) recommended to place the "spores" of the tubercle organism next to the chlamydospores of Mucor and similar fungi. *Semmer* (1895) met again the bright granules in the threads, as well as in the big inflations, of tubercle and glanders bacilli, and saw them when liberated grow up to new rods and threads. And the observations made by *A. Neisser* (1888) with *B. xerosis* were confirmed and extended by *Escherich* (1894) in his work upon the diphtheria bacillus.

A permanent loss of endospore formation was first recorded by *Lehmann* (1888) with *B. anthracis*. The "microspores," which were found in such asporogenous rods, were killed when kept 2–3 hours at 60° C. *Roux* (1890) collected additional experimental evidence upon the same subject, while *Novy* (1894) noticed with an asporogenous strain of *B. oedematis maligni* that moderate heating (1 hour at 58° C.) had no deleterious effect, thereby proving beyond doubt that the easily stainable granules, which were present in and outside of the rods, were more resistant than the vegetative cells and able to act as reproductive organs. The subsidiary rôle played by the "granules" in such cases was already indicated to some extent by analogous

findings with *B. anthracis* and *Megaterium*, made by *DeBary* (1884). *Weibel* (1888), on the other hand, found once more large globular bodies and big club-like inflations within the threads of an asporogenous culture of *B. anthracis*, and *L. Klein* (1889) reported that he obtained, as a "contamination" from a culture of *B. Megaterium* a spore-free "new" *B. allantoides*, which produced large "sausage-shaped" accumulations of "cocci", probably similar to those seen by *Billroth* (1874) and reproduced in figure 44 on Plate N.

A photograph published in the "Atlas" of *Fraenkel* and *Pfeiffer* (1895) of what the authors call "crippled degeneration forms" of *B. Chauvoei*, widely differing from the typical "vorschriftsmässigen" cells, has been reproduced as figure 117 on Plate X (from original fig. 60 on Pl. XXX). It makes an excellent object for comparison with the analogous "involution forms" in *Hauser's* Proteus picture (fig. 120). Rudimentary spore formation is well noticeable in both. In addition, the three figures, Nos. 118, 119, and 121, are equally worth studying. They were reproduced from *Maassen's* (1904) paper on the "involution forms" of the bacteria (original figs. 4 and 7 on Pl. X, and fig. 1 on Pl. XI, respectively), and demonstrate the development of *B. pestis*, *B. lactis aerogenes*, and of *V. cholerae* on lithium chloride agar. The same hardened granules appear in the inflated globular and club-shaped cells. A picture of *B. pyocyaneus*, from salt agar, made by *Matzuschita* (1900) and reproduced as figure 125 on Plate X (from original fig. 26), illustrates the same fact, in reference to which *A. Fischer* has made an interesting hypothetical remark already in 1891, which, however, has never been tried experimentally. It is very probable, indeed, that *A. Fischer* was right when he assumed that by an increase in salt content of the substrate perhaps many bacteria could be induced to form spores, which otherwise are not so inclined. According to our experiments the spores are closely related to the regenerative bodies, and the formation of these reproductive organs is greatly favored by drying. A higher salt concentration in the agar causes the analogous osmotic effect, and it is, therefore, easy to understand why practically all the pictures made by *Matzuschita* and *Maassen* from their salty cultures show various phases in the development of regenerative bodies and gonidangia. The figures 5, 6, 18, 36, 46, 57, 84, 118, 119, 121 and 125 on Plates I–V, VII, and X, which were made from their photographs, are by no means pictures of some quaint and unimportant "teratologic" type of growth, as *Maassen* assumed; in fact, they all illustrate interesting phases in the formation and development of the reproductive organs, as characteristic of the various species.

The same holds true concerning other so-called involution forms, mostly from old agar cultures, shown in the photographic atlasses of *Fraenkel* and *Pfeiffer* (1895) and of *Itzerott* and *Niemann* (1895), some of which have been reproduced as figures 25, 30, 47, 79, and 80 on Plates III, IV, and VII. Others are copied as figures 126–130 on Plates X and XI (from original figs. 7, 16, 46, 60, and 104 in the atlas of the last-named authors) illustrating analogous stages in the development of various spirilla (126), *B. anthracis* (127), *B. capsulatus Pfeiffer* (128), *Vibrio Bonhoff* (129), and *Spirillum rubrum* (130). The characteristic budding of the globular darkly stained bodies is clearly visible in all of them.

Other exceptionally good photographs of regenerative bodies, budding out in a lateral position, were made in 1891 by *Zettnow;* one of them is reproduced as figure 131 on Plate XI (from original fig. 14). But they, too, were discarded as being probably "merely involution forms." Further studies made with impure cultures of *Spirillum Undula* (*Zettnow*, 1896) furnished among others the interesting picture reproduced as figure 132 on Plate XI (from original fig. 16). Round darkly stained and also not stained globular bodies are visible inside, as well as outside, of the spirilla; some of them seem to sprout sideways, and a contaminating rod exhibits also its typical lateral buds. *Zettnow*, however, did not pay any attention to the last-named fact, and the globules of the spirilla are to him simply "vacuoles," though vacuoles of a truly astonishing behavior. *Zettnow* informs us that these "vacuoles" transformed themselves into "globules" of various size, which separated themselves from the parent cell and became free.[1] After having liberated themselves these transformed "vacuoles" exhibited another equally

[1] He says literally, that "die Hohlräume sich in kleinere und grössere Kugeln umwandeln, diese sich abtrennen und schliesslich frei werden."

surprising feature, viz., they were now difficult to stain, and only after having been treated with a mordant ("Loeffler's Beize") they took the stain at least at the outside. Because as *Zettnow* states (contrary to the facts mentioned above) nobody had ever spoken of spores in connection with spirilla; he thinks that he is justified to class these vacuole-globules as signs of degeneration. In another paper (*Zettnow*, 1897) he returns to the subject, after having now worked with pure cultures, which were studied living, stained with methylene blue. Spirilla containing granules were especially actively motile; nevertheless the granules are to *Zettnow* still the mark of degeneration. They are declared now to have been gas bubbles, which persist and agglomerate after the spirilla have died. They gave "fat reaction," too, though they were easily stained by methylene blue; and because they also appeared as "Chromatinmassen," the author is inclined to think—

dass sie bestimmt sind, die Art über die ungünstige Zeit, in welcher die Vermehrung stockt, zu erhalten.

Buds, however, are still to him "krankhafte Degenerationsformen." *Kutscher* (1895 *a*), who had isolated the pure cultures used in these studies, obtained analogous results. He also saw the bright granules within the spirilla and the same characteristically branched forms, as described and drawn by *Sorokin* (see pp. 72 and 96), but because the granules did not show a high resistance against heating, and germination tests apparently were thought to be superfluous, they were declared to be no spores. *Cunningham* (1897), on the other hand, noticed once more that cholera spirilla may be reproduced by coccoid forms. *Kohlbrugge* (1900–1901) recorded analogous results with several water vibrios, and *Nakanishi* (1900) with *V. cholerae*, *V. Finkler-Prior*, and *V. Metchnikovii*. In the latter case the globular bodies were found to predominate in 4-day-old cultures, and after being transferred to new substrates they germinated readily to new vibrios. *Migula* (1897, Vol. I, p. 157), however, was of the opinion that the round bodies, which *Perty* had found with the spirilla, had been—

. . . andere Organismen, da sie teils endständige, von dem Spirillum durch eine Scheidewand deutlich getrennte, teils irgendwo dem Rücken aufsitzende, keinerlei genetischen Zusammenhang mit dem Spirillum bekundende Kugeln sind.

Undoubtedly, *Migula* had not read the careful description given by *Perty*, quoted on page 91, otherwise he would not have made such an incorrect statement. Furthermore, it is not without interest, that he himself (*Migula*, 1904) published a photograph of some spirilla, reproduced as figure 133 on Plate XI (from original fig. 8 on Pl. II), showing exactly the same body, or "foreign organism" according to his opinion, attached to the "back" of one of the spirilla in his own preparate. This picture should also be compared with figure 130 (*Spir. rubrum*, photographed by *Itzerott* and *Niemann*). Another photograph given by *Migula* (1904) on the same plate, has been reproduced as figure 134 on Plate XI. It was destined to illustrate the flagellation of *B. proteus*, but it exhibits in addition the round bodies characteristic of this species. How little *Migula* knew, indeed, of the reproductive processes common among the bacteria, and about the literature covering this subject, is very clearly indicated by the manner, in which he refutes in the last-named publication (1904, p. 61) some observations made by *Trambusti* and *Galeotti* (1892) concerning the formation and liberation of gonidia, though they were in complete accordance with the earlier findings of *Perty*, *Billroth*, *Ewart*, *Toussaint*, *Künstler*, *Finkler* and *Prior*, *Ferrán*, *Artigalas*, *Maddox*, *Schroen*, *Tomaschek*, *Dowdeswell*, and others cited above. To *Migula* such an occurrence is simply impossible:

Ein solcher Vorgang kommt bei den Bakterien der ganzen Art und Weise ihrer vegetativen Entwicklung nach nicht vor.

In figure 53 on Plate N another example of this "impossible" mode of reproduction is shown, as it was drawn by *Babes* (1895, original fig. 13 B) when he studied Ascobacterium luteum. Formation, multiplication, and upgrowth, as well as liberation, of gonidia and young rods are all well visible.

More evidence concerning the occurrence of globular reproductive organs with various nonspore-forming bacteria, especially with *B. typhi*, *dysenteriae* and *V. cholerae*, was furnished in a series of important contributions by *E. Almquist* (1893–1917), who especially emphasized,

that if we keep the bacteria in the laboratory under conditions more similar to their natural environment, they will reveal at once much more of their life history than they are able to exhibit under the monotonous artificial conditions under which they are usually compelled to live. At first it was shown (*Almquist*, 1893) that *B. coli*, as well as *B. typhi*, when grown at a low temperature (10–11° C.) in manure soil, produce by fragmentation, as well as by budding, very small round bodies, which transferred to new substrate (broth) at room temperature quickly reproduce new normal, often also curved, rods. Further studies (*Almquist*, 1904) added to the small ones larger round bodies, which were called "conidia" by the Swedish author, and which were also found to bud out at the side or at the end of the vegetative cells, often supported by a short stem. They were discovered in both cholera and typhoid cultures, especially when 2–3 per cent NaCl had been added to the substrates. They were easily stainable and reproduced readily on new substrates each one or two small, very motile, young vegetative cells. With cholera the germinating rod looked at first very much like typhoid, while in the latter case the first generation was extremely thin ("nadelartig"). It was noticed, too, that these "conidia" are able to multiply as such by budding. All these findings were confirmed and extended in the publications of 1906–1908; they are mostly based on direct observations of the living material. In the 1907 paper *Almquist* compares his conidia with the reproductive organs of the iron bacteria, also called by him "conidia." Some drawings published in 1908 are reproduced as figure 54 on Plate N (from original figs. 5, 13, and 21). It must be admitted that they are not very impressive, but everybody who has had some experience in this direction will acknowledge their accuracy. But it was not until 1916 and 1917 that good photographs were also furnished by *Almquist*. Five of them are reproduced as figures 135–139 on Plate XI (from original figs. 4, 5, and 23 in the 1916 and figs. 1 and 4 in the 1917 papers), illustrating formation and development of the "conidia" of *B. typhi* (figs. 135, 136, and 138), *B. dysenteriae* (fig. 137), and *V. cholerae* (fig. 139). Besides these species, *B. diphtheriae*, *B. acidi propionici c*, several micrococci and coli-like organisms were also studied. A considerable number of the experiments was made with single-cell cultures; dried agar kept at 10–14° C. proved to be especially favorable for stimulating the development of these round reproductive forms. It is obvious that *Almquist's* discoveries are in complete agreement with many earlier, as well as with more recent, observations made along similar lines; but probably nobody has followed so patiently and extensively the formation, multiplication, and germination of what we now call gonidia and regenerative bodies, as *Almquist* did.

That his findings were contested by authors like *Gotschlich* (1909) and *Kruse* (1910, pp. 8 and 31) is not surprising, but does certainly not reduce their great value to any extent. On the other hand, it is again rather interesting to compare these pictures of *Almquist* with some others contained in various papers and textbooks, which reveal the same details, though as a rule, this was not noticed or at least not mentioned, by the respective authors themselves. Figure 140 on Plate XI is a reproduction of a photograph made by *Friedrich* (1892, original fig. 4 on Pl. V) from a 4-day-old cholera culture. Figure 141 is the picture of a young Pyocyaneus culture, published by *Muir* and *Ritchie* (1903, original fig. 69); it should be compared with figure 31 on Plate III, showing the same process, i. e., germination of gonidia and of regenerative bodies, with the plague bacillus, photographed by the same authors, and with figure 136 on Plate XI (germinating gonidia and regenerative bodies of *B. typhi*, *Almquist*). Figure 142 was made from *Günther's* textbook (1906, original fig. 54), presenting the development of regenerative bodies of *B. enteritidis*. Figure 143 illustrates the same process with *B. ochraceus* as photographed by *Migula* (1900, Vol. II, Pl. XI, fig. 3), and as figure 144 another picture made by the same author (*Migula*, 1900, Vol. II, Pl. XVII, fig. 5) has been added, presenting a *Spirillum "sporiferum."* Of special interest, however, is figure 145, made after a picture published by *Kitt* (1899, p. 393), wherein numerous regenerative bodies are visible, budding out at the side or at the end of the rods, belonging to a *Bac. phlegmasiae uberis* (a member of the Aerogenes group).

That the colonies growing on the plate sometimes contain nothing but such round regenerative bodies, is illustrated by two photographs made by *Axelrad* (1903), reproduced as figures

146 and 147 on Plate XI. The former shows a contact preparate of *Streptococcus lanceolatus;* its large budding cells are especially noteworthy. The latter was taken from a colony of *B. coli.*

A rôle played by the gonidia in the multiplication of the bacteria, and the parallelism indicated thereby between tricho- and other bacteria, are also shedding some more light upon the physiological significance of the clubs formed by Mycobacteria and Actinomycetes, as well as by many other bacteria. As figure 43 on Plate L an old drawing, made by *F. Cohn* (1870), was reproduced, showing an interesting "club," attached in a lateral position to a Crenothrix thread, and considered by the author to be of a spore-like character. On Plate J as figure 34, a drawing by *Babes* (1895) was given, presenting clubs produced by a diphtheroid organism, one of them containing four small granules, while in the other one a larger spore-like body is visible. On Plate B as figure 3 another drawing made by the same author may be found; one of the Streptococcus chains sketched therein, has also attached to its side a club, which resembles very closely the Crenothrix club of *Cohn.* That the gonidia, or "spores," as *A. Neisser* called them, which are contained in the club-shaped cells of the diphtheriod bacilli may according to this author's observations (*A. Neisser,* 1888) germinate therein and grow out sideways was mentioned on page 97. In addition, on page 98, quotations from *MacFadyean* (1889), *Bostroem* (1890), and *Eppinger* (1890) have been given, which also indicated that relations seem to exist between the production of gonidia ("spores") within the threads of Actinomyces and the formation of the characteristic clubs. Concerning the latter *Crookshank* (1896, p. 437) made the following important statement:

> These club-shaped bodies represent organs of fructification, rather than the results of degeneration or death. The difficulty in accepting the view of their being entirely lifeless forms lies in the fact that the author has observed daughter cells growing from the mature clubs; and, further, in the bovine fungus the author has been able to trace the stages in the development of a single club to a completely formed rosette.

As figure 55 on Plate N a drawing, made by the same author (*Crookshank,* 1896, original fig. 12 on Pl. XI), has been reproduced, showing tubercle bacilli taken from the liver of a Rhea, with swellings at the ends of the rods, which were said to be "very suggestive of spores." Whether the apparent germination of some of the liberated "spores" visible in the picture has been a true sprouting was not ascertained. Some years earlier, however, *Coppen-Jones* (1893) had reported that he saw clubs of the tubercle bacilli grow out into numerous short hyphae, and later *Conradi* (1900) recorded the same occurrence with *B. mallei:* fine short lateral threads being produced by clubs, as well as by the older broad threads.

On the other hand, *Olsen* (1897) has emphasized that spore-forming bacilli, too, may assume the appearance of an Actinomyces. His drawing of *B. mycoides* grown in sand was reproduced as figure 20 on Plate F. It should be compared with *Babes'* sketch of a clubbed diphtheroid bacillus mentioned above, as well as with the picture of *B. tuberculosis* made by *Metchnikoff* (see fig. 38 on Pl. J) and with the description of *B. diphtheriae* given by *Hill* (quoted on p. 78). As in these two cases, the breaking off of clubs in the shape of oval bodies from the end of side branches of *B. mycoides* is clearly visible in figure 20, but in addition the formation of endospores within the clubs is also well illustrated. According to the Norwegian author the same phenomenon, viz., the production of one endospore within each club, was noticed with several cocci, sarcinae, and with other bacilli. A drawing made by *Dangeard* (1891) of his "*Eubacillus multisporus,*" reproduced as figure 56 on Plate N (from original fig. 4 on Pl. VIII), wins new interest in this connection. And it is worth mentioning, too, that on the one side *Olsen's* view is supported by analogous findings with spore-forming bacilli reported by *Cozzolino* (1900) and by *Johnson* (1912), on the other side by some observations made by *Babes* (1907 *a*) with *B. leprae,* and by *Schütze* (1908) in regard to *Actinomyces monosporus.* According to the first-named author the branched forms of *B. leprae* are inclined to produce terminal clubs, staining at the outside like the normal cells, while the bright center reacts like a spore; and *Schütze's Actinomyces monosporus* is characterized by always producing only one oval spore at each branch, which, though still easily stainable, was found to display a higher resistance than other Actinomyces spores. *Loele* (1908) at the same time secured further evidence, that at least some of the Actinomyces clubs clearly exhibit their character as

reproductive organs, viz., those containing numerous granules. They were classed by the author as "sporangia."

A very interesting drawing of what we now call regenerative bodies, made by *Henneberg* (1898) of an acetic acid bacterium (*Bact. oxydans*), is reproduced as figure 57 on Plate N (from original figure 1, whose magnification evidently was not properly determined). It furnishes a very clear insight into the mode in which these bodies are formed. The same reproductive organs were seen by *Henneberg* (1901) also with several lactobacilli, where they are, indeed, most frequent, but it is not easy to understand how the author, after having made those sketches of the acetic acid bacteria, now can state without hesitation:

> An den Zellen kleben häufig mehr oder weniger grosse tropfenförmige Ausscheidungen aus den Nährflüssigkeiten, die den Zellen ein ganz verändertes Aussehen geben können.

B. Lindneri is declared to have shown "fettartige Ausscheidungen aus den Nährflüssigkeiten an den Zellen festgeklebt."

Tissier (1900) obtained the same round bodies with his *B. bifidus*, but he was careful enough not to discard them without trial; therefore, he was able to report:

> De ces boules partent en rayonnant des corps bacillaires d'une grande finesse qui se subdivisent.

Sandberg (1904) made some good photographs of regenerative bodies attached to lactobacilli taken from the stomach, though not noticing them. *Weigmann, Gruber,* and *Huss* (1907) made pictures of the same "bulb-like inflations" growing at the end or at the side of lactobacilli from matzoon, and *Kuntze* (1908) photographed those of *B. bulgaricus*. None of these authors, however, saw them germinate. As figure 148 on Plate XI one of our photographs of *B. bulgaricus* (*Löhnis* and *Smith*, 1916 *a*, fig. 29) has been reproduced, showing two regenerative bodies in their characteristic position and also (below the upper one) two thin threads parting at the same place from a broader rod.

Analogus things have been repeatedly photographed. *Maassen* (1904), for instance, published a picture of a spore-forming bacillus isolated from chopped meat ("Hackfleisch"), which was reproduced as figure 149 on Plate XI (from original fig. 4 on Pl. XI), where it makes an interesting counterpart to our photograph of *B. bulgaricus*, as well as to *Olsen's* drawings of spore-forming clubs. In the textbook of *Hiss* and *Zinsser* (1914, p. 576, fig. 125) *B. subtilis* is photographed as reproduced in figure 150 on Plate XI, but in the text nothing is said concerning this remarkable outgrowth.

Small coccoid reproductive organs of *B. coli*, like those discussed by *Almquist* (1893), were closely studied by *Adami, Abbott,* and *Nicholson* (1899) and by *M. E. Abbott* (1900). To some extent they behaved like vegetative cells and were mentioned, therefore, already on page 56 But their ability to reproduce normal rods was also well noticeable. The authors connect them with the so-called polar granules, so common in *B. coli* and related species, and also with the "beading" often shown by the tubercle bacilli. Furthermore, *M. E. Abbott* points out that like *B. coli* other bacilli, too, may undergo such changes in the body, so that in fact many of the "granules" occurring within the tissue may be reproductive organs of different bacilli. A similar view has been expressed by *Wertheim* (1899) in regard to the gonococcus, as well as to staphylo- and streptococci. The small granules produced by these organisms are considered to be the reason why occasionally infections may be caused, though no cocci can be found. *N. K. Schultz* (1901) obtained analogous results concerning the plague bacillus. She observed directly in the hanging drop the upgrowth of the granules into normal rods, as shown on Plate O in figure 58, which was reproduced from her first paper (1901 *a*, original fig. I). Other interesting data have been furnished by *Rothert* (1902), unfortunately in a not easily accessible Russian dissertation entitled "Degeneration and Regeneration of the Bacteria." It was pointed out in this paper, probably for the first time, that all bacteria during their period of "degeneration" produce more or less resistant granules, which are enabled to act under suitable conditions as organs of "regeneration." The following species were studied, all with positive result: *Staphylococcus pyogenes aureus, Streptoc. pyogenes, B. coli, B. typhosus, B. pneumoniae, B. capsulatus Pfeiffer, B. rubidis, B. arborescens, Vibrio cholerae, V. Milleri;* and

it was especially criticized, with good reason, that too many bacteriologists are always ready to discard all cultures showing "granular decomposition" as dead, without having them first thoroughly tested. *Fedorowitch* (1902), another Russian bacteriologist, added important observations upon the germination of the "granules" produced by several cocci, *B. pyocyaneus, typhosus, coli, septicaemiae murium, cholerae gallinarum, diphtheriae,* and *tuberculosis,* which he studied in the hanging drop and for which he proposes the name "protospores," because they are, according to his opinion, reproductive organs similar to the regular endospores, though not reaching the full development and the high resistance of these latter forms. With his Enterococcus, *Thiercelin* (1903) found out that small granules, which the French author calls "microblastes," increase in size step by step until they reach again the normal size of the coccus. In addition, *Thiercelin* and *Jouhaud* (1903 *a*) discovered that the microblasts are produced by the liberation of the "granulations périphériques," which are growing within the cell alongside with the "taches centrales," which participate in the cell division. In some cases "un fin pédicule" was seen connecting parent cell and microblast. *Grassberger* (1903) saw and discussed formation and liberation of similar granules by *B. Chauvoei.* He describes the process as "Abschnürung unreifer Sporenanlagen" and makes in this connection the very appropriate remark:

> Gewöhnlich werden bei mikrophotographischen Darstellungen sporulierender Bakterien solche Stellen vermieden, in denen sich derartige losgetrennte Sporenanlagen vorfinden, da sie eine verdächtige, allerdings nur morphologische Ähnlichkeit mit Kokken aufweisen.

His photograph (original fig. 67) has been reproduced as figure 151 on Plate XI, where it furnishes a good counterpart to figure 152, a copy of a photograph made by *Winogradsky* (1902, original fig. 1) from his Clostridium Pastorianum. The coccoid forms are easily discernible, in reference to which the author says:

> An den Fäden beobachtet man manchmal einen seltsamen Vorgang, nämlich die Abschnürung von kleinen, kokkenartigen Gliedern in mässiger Menge, welche, soviel ich weiss, nicht mehr entwicklungsfähig sind.

Experiments with several nonspore-forming bacteria (*Pseudomonas cerevisiae, fluorescens* and related forms) led *Fuhrmann* (1906–1913) to the conclusion that some of the metachromatic granules appearing within the cells, especially within the club-shaped ones, are reproductive organs to be compared with the endospores produced by the spore-forming bacilli. That he was not correct in regard to the second statement is beyond question. All bacteria, spore-forming and nonspore-forming alike, use their gonidia as one mode of multiplication and reproduction, while the more or less highly resistant endospores have their special task as resting forms, in which respect they can be replaced by the gonidia only to a very limited extent. But *Fuhrmann* was undoubtedly right in regard to the reproductive character of the "granules" studied by him, and it is only to be regretted that also his careful studies have not been considered and tested adequately. The development of new rods from the granules in the clubs and their liberation, as studied by him in the hanging drop, prove once more that this process is by no means so "impossible," as it was declared to be by *Migula* (1904).

That coccoid reproductive organs may play an important part in the life history of the tubercle bacillus was already indicated by those early observations of *Klebs, Babes, Malassez* and *Vignal, Biedert* and *Sigel,* and others, mentioned on page 95, by which it was also ascertained that some of these granules are acid-fast like the bacilli,while others are not, but that these can be stained by a modified Gram method, worked out by *Biedert* and *Sigel. Schürmayer* (1898 *a*), too, noticed that smaller and larger not acid-fast granules may be formed by the tubercle bacillus, which in their turn reproduce typical rods and are, according to this author, "undoubtedly spores." To globular bodies of the tubercle bacilli seen by *Arrigo,* which were reproduced from his drawings as figures 103 and 104 on Plate IX, are probably also to be classed, at least in part, as reproductive organs. The Italian author called them "germ granules" (Keimkörnchen). *Chester* (1901, page 14) was of the opinion "that these granular particles" (replacing the tubercle bacilli in old lesions) "are resting bodies of the nature of gonidia, which are capable of reproducing the species." What *Spengler* (1905–1907) described as fragments ("Splitter") of the tubercle bacilli is evidently of the same class; later they were declared by

him and by *Betegh* (1908) to be "spores." *Much* (1907–1909) paid special attention to the not acid-fast but Gram-positive granules. He emphasized strongly that they never had been seen before and that they were "entirely" different from the acid-fast globular bodies studied by *Spengler* and others. That both statements are not valid can be easily seen from the earlier publications, as well as from those contributed more recently by *Fuchs-Wolfring* (1908), *Knoll* (1910), *Fontes* (1910), *Kirchenstein* (1912), *Heinrich* (1912), and others. The acid resistance of these globular bodies naturally changes like that of the rods. Their slipping out of the sheath and their ability to reproduce small rods, which afterwards grow up to normal size, has been repeatedly observed by these authors. *Fontes'* paper is of special interest, because the filterability of a part of these "granules" was also studied in this case, and *Heinrich* has shown that "Much's granules" are equally present in Corynebacteria, *B. erysipelatos suum* and other not acid-fast, but Gram-positive species. *Rosenblat* (1905), too, observed in the hanging drop, that granules were formed within tubercle, leprosy and other bacilli, which were liberated after 7–9 days and then grew up to new rods and threads. But later (1911) she made the following somewhat surprising statement:

> Es liegen keine Beweise dafür vor, dass die Muchschen Granula Entwicklungsformen oder Dauerformen der Tuberkelbacillen sind.

Leschke (1911) tried to correct this mistake.

With the diphtheria bacillus and its relatives the situation is very similar; but the contributions upon this subject are less numerous. "Cocci" have always played an important role in the diagnosis of diphtheria, as well as in the cultures obtained in such cases, from the time of *Oertel* (1871) until recently (*Walker* and *Adkinson*, *Mellon*, *Heinemann*, 1917), as was discussed on pages 77–81. *A. Neisser's* work on the "spores" of *B. xerosis* was mentioned in this chapter (p. 97). In addition, it may be quoted that *Babes* in a few cases found heat-resistant spores with genuine diphtheria bacilli (*Cornil* and *Babes*, 1890, Vol. II, p. 59), and *Chester* (1901, p. 14) thought it very likely "that the granular segments which they often produce are of the nature of gonidia." Additional interesting data are to be found in a paper upon the "Klebs-Löffler bacillus," written by *Bergstrand* (1918).

Coccoid reproductive bodies in leprosy have been also seen quite frequently. Besides those early discoveries of *A. Neisser*, *G. A. Hansen*, *Babes* and *Lutz*, the more recent findings of *Betegh* (1908) and *Kedrowski* (1910) are to be mentioned. Both authors studied especially those only partially acid-resistant forms, which were reproduced in figures 153 on Plate XI and 154 on Plate XII (from *Kedrowski's* original fig. 38 on Pl. VII). The latter are presenting an interesting counterpart to the round bodies found by *E. de Negri* (1916) in serum cultures of Corynebacteria, reproduced as figure 101 on Plate IX, and to similar round cells discovered by *Ghon*, *Mucha* and *Müller* (1906) in meningitis, here acting as reproductive organs of the anaerobic bacilli, shown in figure 10 on Pl. C. Figure 155 on Plate XII is a reproduction of the growth found in cuts from the brain (original fig. 3); figure 156 presents the typical appearance of the regenerative bodies grown anaerobically on glucose agar (original fig. 18); and figure 157 is a copy of a drawing made by *Neelsen* as early as in 1880 (original fig. 9 on Pl. XI) of the regenerative bodies of *B. cyanogenes*. This author already found out that the round bodies, which he compares with small yeast cells, are the result of the upgrowth of the gonidia formed by the rods, that they are either motile or immotile, that they stain very darkly, and that they are able to reproduce the normal rods when transferred at the right time.

The round bodies visible in figure 158 on Plate XII, photographed by *Hammerl* (1906, original fig. 4), belong to *V. cholerae*. *Bittrolff* (1912) and *Stamm* (1914) studied the same motile, budding globules, which were seen to germinate under suitable conditions to typical cholera bacilli.

Most extensive studies upon these "granular" and "globular" reproductive organs, which we call the gonidia and regenerative bodies of the bacteria, have been made within the last decade in regard to the spirochaets. It is evident that so much valuable material was secured in this case, because the investigators, most of them coming from the protozoological side, have not been blinded by the adverse bacteriological doctrine, and, therefore, they succeeded

despite the fact that these modes of reproduction are much more difficult to study with spirochaets than with any of the common bacteria. *Dutton* and *Todd* (1905), *Castellani* (1905), *Wechselmann* and *Löwenthal* (1905), *Leuriaux* and *Geets* (1906), *Krienitz* (1906), *Breinl* and *Kinghorn* (1906), as well as *Perrin* (1906), have furnished the earliest contributions, establishing the fact that "metachromatic" or "chromatine" granules produced within the spirochaets may either multiply as such and replace the spirochaets temporarily in the organism, or eventually reproduce the long forms, and that not infrequently larger "bulbs" are visible at the side or at the end of the spiral organisms, which also seem to act as reproductive organs. That cysts formed by coiled spirochaets may equally participate in this process was made probable by the investigations of *Breinl* (1907) and of *Dutton* and *Todd* (1907). Among the numerous further studies which tried to elucidate these difficult problems those of *Leishman* (1909–1918), *Balfour* (1911–1913), *Fantham* (1911), *Hindle* (1911), *Noguchi* (1911–1912), and *Henry* (1913) may be mentioned here. An illustration by *Fantham* (original fig. 5) has been reproduced as figure 59 on Plate O. The formation and liberation of the "spores" as shown here, invites a comparison with *Perty's* old drawing of granulated spirilla visible in figure 42 on Plate L, and with the liberation of the gonidia by some bacteria as it was drawn by *Billroth* and reproduced in figures 44 and 45 on Plate L. Two drawings made by *Bosanquet* (1911 original figs. 21 and 22) of *Spirochaeta anodontae* may be added as figure 60 on Plate O. It is interesting to see how very closely the results of these new studies upon the life history of the spirochaets agree with those recorded nearly 40 years ago by *Heydenreich, Guttmann* and *Albrecht,* which were mentioned on p. 94.

As figure 159 on Plate XII a photograph of an anaerobic bacillus, probably belonging in the Fusiformis group, has been reproduced, which was made by *Rosenow* and *Tunnicliff* (1912, original fig. 3 on Pl. I). Liberated "granules" are well visible, as is also their escaping and budding out from rods and threads.

That the gonidia of pathogenic bacteria may play an important rôle as filterable vira and cell inclusions has been emphasized by *Herzog* (1910–1913) with regard to the Gonococcus. The observations upon the "infective granules" of the spirochaets in tick fever, and spirochaetosis of fowls, recorded by *Leishman, Balfour* and others of the authors just mentioned, the relation between spirochaets and filterable virus in hog cholera, as discussed by *Rüther* (1910) and *King* et al. (1913), and the recent discoveries of *Rosenow* et al. (1916–1917) upon the small forms of a Streptococcus as causative agent in poliomyelitis, as well as those of *Hort* and his collaborators, to be discussed presently, indicate beyond doubt that these problems will become the more important the more thoroughly the gonidia of the bacteria will be studied.

In some experiments carried out with *B. bifidus Noguchi* (1910) was able to demonstrate for the first time that it is possible to induce regular spore formation with otherwise not spore forming bacilli, and also to cause their reversion to the original type.

The first special information upon gonidia and regenerative bodies ("Regenerationsformen"), produced by Azotobacter, was furnished by *Prażmowski* (1912, p. 145, 167), and of still greater value are additional investigations of the same author (*Prażmowski,* 1913), wherein he reached the conclusion that probably all bacteria are able to liberate small granules of nuclear material which act as reproductive organs. The first photographs of the flagellated gonidia of Azotobacter made by *D. H. Jones,* have been reproduced as figure 160 on Plate XII (from original figs. 9 and 10 in Pl. V); although not clearly defined they illustrate the liberation of the gonidia from the disintegrating larger cells, and with some difficulty their long cilia may be discerned. Another photograph, reproduced as figure 161 on Plate XII, was made by *Marrassini* (1913, original fig. 28 on Pl. I); it shows several gonidia of *B. subtilis,* a few of them with long single cilia, though the author himself had only in mind to show the capsule and flagella around the Subtilis rods, apparently not noticing the many round bodies, despite their predominance.

A casual observation concerning endospore formation in some or our old Azotobacter cultures led to the discovery of the striking pleomorphism of this group of organisms (*Löhnis* and *Hanzawa,* 1914). Copies of three of the photographs published in this paper were given as

figures 19–21 on Plate II; the breaking up of the larger cells into the smaller "granules," first discussed by *Prażmowski,* is clearly visible in the first two of them. The perfectly round forms of medium size, which were also shown in one of the photographs of that paper, reproduced as figure 68 on Plate VI, are to be classed as regenerative bodies. A comparison of this picture with figure 35 on Plate III (*B. pestis, Rowland,* 1914), figure 59 on Plate V (*B. anthracis, Henri,* 1914), figure 91 on Plate VIII (*B. mallei, Carpano,* 1913), figures 101 and 104 on Plate IX (*Corynebacterium, E. de Negri,* 1916, and *B. tuberculosis, Arrigo,* 1900), figures 154, 156, and 158 on Plate XII (*B. leprae, Kedrowski,* 1910, the anaerobic meningitis bacillus of *Ghon, Mucha* and *Müller,* 1906, and *V. cholerae, Hammerl,* 1906) will make it clear that the surprising uniformity of this globular type of regenerative bodies as produced by all groups of bacteria is certainly a point of considerable importance.

In his "Studien über die Fortpflanzung von Bakterien, Spirillen and Spirochaeten" *Meirowsky* (1914 *b*) has furnished very valuable information upon the production and development of gonidia and regenerative bodies by representatives of different groups of bacteria, once more demonstrating the general occurence of these modes of reproduction. Many details secured by him, will have to be discussed on the following pages. As figures 162–167 on Plate XII some of his drawings are reproduced, illustrating what he calls the formation of "buds" and "umbels" ("Knospen" and "Dolden") by B. *tuberculosis* (figs. 162–164), *B. leprae* (figs. 165–166), and by *Spirillum rubrum* (fig. 167). But *Meirowsky,* too, furnishes an excellent example of what disadvantageous effect may result from an uncritical submission to the prevalent theory, when he concludes from his observations, that tubercle and leprosy bacilli should be separated from the bacteria on account of their forming "buds" and "umbels," and should be placed among the fungi, because, according to his opinion, such modes of multiplication and reproduction are entirely absent in bacteria; and yet he himself found exactly the same facts with *B. paratyphi B, B. enteritidis,* spirilla and spirochaets, and concludes, on the other hand, that the spirochaets, therefore, ought to be classed among the bacteria. The following quotations will prove this curious lack of logic.

Das Auftreten von Seitenknospen, Dolden and Seitenzweigen stellt die Tuberkelbacillen ausserhalb der Reihe der Bakterien und lässt sie zu höheren Pilzformen in Beziehung treten, in deren Entwicklungskreis sie vermutlich gehören (p. 11).

Betrachtet man den Leprabacillus vom rein morphologischen Standpunkt, so ergiebt sich, dass er nicht zu den Bakterien gerechnet werden kann, da bei diesen nur die Vermehrung auf dem Wege der Querteilung und Sporenbil dung stattfindet (p. 15).

Concerning *B. paratyphi B:*

Auch hier zeigt sich wieder, dass ein kugliges Gebilde ausserhalb des Bacillenleibes liegen und mit ihm durch einen feinen Stiel verbunden sein kann; (und es) sind teils gegliederte, teils ungegliederte Fäden vorhanden, die an ihren Enden eine Dolde tragen (p. 15, i. e., on the same page bearing the statement in regard to the leprosy organism).

Concerning *B. enteritidis:*

Neben ihm lag häufig ein kugliges oder auch mehr längliches Gebilde, das in zahlreichen Fällen mit ihm durch einen Stiel verbunden war . . . Die weiteren Bilder zeigen, . . . dass diese Knospen . . . zu langen . . . Fäden auswachsen können. Diese Gebilde weisen häufig . . . kuglige Auftreibungen, Seitenknötchen und vor allem Seitensprossen und Verzweigungen auf (p. 16).

Concerning spirochaets:

Es muss . . . betont werden, dass dieser Knospenbildung eine ausserordentliche Bedeutung fürdie Vermehrung der Spirochaeten zukommt (p. 59).

That, in fact, the processes studied by *Meirowsky* are quite general with and typical for all bacteria, and that, therefore, they can not be used as a reason for separating tubercle and leprosy organisms from other bacteria, has been presented, moreover, by *Meirowsky* in the same paper very clearly in a graphic summary (Pl. XVIII), which has been reproduced as Plate XIV.

Evidently without knowledge of this German publication *Hort* in England published a series of reports (*Hort* et al., 1915–1917), which on the one side furnish much confirmative material with regard to *Meirowsky's* and *Almquist's* discoveries, and on the other side open a wide new field for further research upon pleomorphism and reproduction of the bacteria, especially in

connection with the so-called filterable vira. On Plate XIII as figure 178 a collection of drawings made by *Meirowsky* (original plate III), illustrating the various phases in the life history of *B. paratyphi B*, has been placed side by side with two pictures made by *Hort* (1917*a*, original figs. 1 and 2) of *B. typhosus* (fig. 179), and of *B. coli* (fig. 180), which deserve to be studied closely. The remark made by *Adami* (1916) after having become acquainted with *Hort's* investigations, which was quoted on p. 10, will present itself as being, indeed, very appropriate, when considering the many data discovered or rediscovered recently with regard to bacterial reproduction, which have always been discarded by the "simplicity" doctrine, still widely prevailing among bacteriologists and in bacteriological literature. With the meningococci *Hort* (1917*b*) once more discovered that type of multiple production of gonidia within the enlarged parent cell, which was declared by *Migula* to be "impossible," though, in fact, it has been studied by many investigators and is so common with all groups of bacteria that *Hort* undoubtedly was mistaken when he thought the Meningococcus must be placed among the Hemiascomycetes on account of its "gemmation and multiple endosporulation."

A short summary of our own investigations upon the different modes of bacterial reproduction (*Löhnis* and *Smith*, 1916*a*) was quoted on p. 90, and several details will have to be mentioned on the following pages. Some of our photographs, which were demonstrated at the New Haven meeting of the "Society of American Bacteriologists" (1916*b*), are reproduced as figures 168–176 on Plate XII, illustrating formation and liberation of gonidia of *Micr. candicans* (fig. 168) and *M. luteus* (fig. 169), development of the regenerative bodies by *Streptoc. lactis* (fig. 170), *B. pneumoniae* (fig. 171), and *B. bulgaricus* (fig. 172), germination of regenerative bodies of *Azotobacter Beijerinckii* (fig. 173), development of new small organisms from the gonidia while still connected with the parent cell (fig. 174, *B. fluorescens*; fig. 175, *Azotob. vinelandii*) and a star-like upgrowth of small rods from an agglomeration of unstainable gonidia liberated from the large darkly stained cells of *Azotob. chroococcum*, visible in the lower part of the picture (fig. 176). The many relations to and confirmations of earlier observations quoted on the preceding pages are evident. And it is equally obvious that the various forms visible in figure 177, which is a reproduction of a photograph made by *Goadby* (1917, original fig. 14) of a bacillus isolated from gas gangrene, which could not be identified "owing to the curious method of growth," are an interesting collection of gonidia, regenerative bodies and endospores.

It goes without saying that, like the pleomorphism of the bacteria in their vegetative stage, so also their different modes and organs of reproduction will necessitate much more thorough investigations than those generally en vogue now as at *Robert Koch's* time. It is easy, but not scientific, to get quickly rid of all unexpected facts by declaring them to be involution forms, contaminations, artefacts, plasmolysis, plasmoptysis, etc., without making any special test. Such special tests, however, are of course indispensable if correct results are to be obtained.

(b) DIFFERENTIATION BETWEEN REPRODUCTIVE ORGANS AND OTHER CELL PRODUCTS AND ARTEFACTS.

Undoubtedly, the reproduction of a new bacterium is the only fact by which it is possible to decide with absolute certainty whether or not a problematic body is a reproductive organ of a bacterium. The observation of active motility often shown by the gonidia, and sometimes by regenerative bodies, too, furnishes also fairly conclusive proof. In many cases, however, the examination of the stained preparate must be used as basis for judgment, and here the road is beset with numerous pitfalls. Thus far many investigations have been made upon the bacterial cell and its content, without paying any attention whatever to the possibility, that some of the cell products might have been reproductive organs other than endospores in different stages of their development. It is not only probable, but even certain to some extent, that among the cell inclusions described as nuclear material, chromatin, metachromatic granules, volutin, glycogen, fat and other reserve material, as well as vacuoles, growing gonidia and regenerative bodies have been included, because their staining reactions, changing in the course of their development, have established an apparent relationship to the one or to the other class of cell products. Detailed studies, as have been made in this respect with

growing endospores, are nearly entirely missing at the present time with regard to the other bacterial reproductive organs. Nevertheless, the cytological results collected so far also contain several valuable indications, which may be helpful for further research; therefore, they will have to be considered first.

The time is not far back when there was much discussion concerning the presence or absence of a nucleus in the bacterial cell. The results available now, though by no means final, can be accepted, however, as sufficient evidence that arrangement or distribution of the nuclear material changes during the life of the bacterial cell and varies to some extent with the different species. Uniform distribution, similar to the "chromidia" in the protozoa, arrangement in circles, spirals, zigzags, rods, chains, or filaments, as well as concentration into one or two distinct bodies, displaying the qualities of true nuclei, have all been observed within the same cell and with representatives of very different groups of bacteria. Publications by *Zukal* (1896), *Vejdovsky* (1900–1904), *Mencl* (1905–1911), *Perrin* (1906), *Swellengrebel* (1906–1909), *Guilliermond* (1908), *Růžička* (1908–1909), *Hölling* (1910), *Dobell* (1911), *A. Meyer* (1912), *Prażmowski* (1912), and *Luska* (1914) have accumulated much valuable material in this respect, against the older widely divergent views held by *Bütschli* (1890–1896), *A. Fischer* (1897–1903), and *Migula* (1897). It can not be further doubted that nuclear material plays the same important rôle in regard to growth, division, and multiplication of the bacterial cells as it does in the cells of the higher organisms. That it will always participate in the formation of reproductive organs is equally beyond doubt, despite the scantiness of experimental proof available at present.

Some interesting observations concerning the production of zoospores have been made by *Zukal* (1896) in connection with his cytological studies. He noticed that the nuclear granules, which he calls "microsomes" and which he found to be frequent in bacteria, protozoa, and Cyanophyceae, are able, especially in the latter case, to assume under certain circumstances the character of regular zoospores. That the chromidia of protozoa may reproduce new cells has been recorded very often. Motility, fission, and participation of "chromatin granules" in the division of the bacterial cell have been studied by *Babes* as early as in 1885. Their predominant part in the formation of bacterial endospores has become known especially by the investigations of *Zettnow* (1899), *Schaudinn* (1902–1903), *Guilliermond* (1908), *Růžička* (1908–1909), *A. Meyer* (1912), and *Swellengrebel* (1913). That the spores of Actinomyces are also of nuclear character was pointed out by *Neukirch* (1902), and the granules (i. e. gonidia) of the tubercle bacilli were declared by *Fontes* (1910) to be made up prominently of paranucleo-albumin. The so-called sporoids, replacing sometimes the regular endospores in spore-forming bacilli, are also chemically equivalent to them, as far as can be derived from microchemical analysis, according to *Růžička* (1908–1909) and *Petschenko* (1913). The formation of the so-called spores (i. e. gonidia) of *Spirillum volutans* went on, as was pointed out by *Amato* (1908), practically in the same manner as the formation of the endospores in *B. mesentericus*, *subtilis*, and *mycoides*. That some of the nuclear material may leave the old cells has been noticed by *Rowland* (1899) and by *Mencl* (1911), but it is to be doubted whether this is merely an excretory process, as these authors are inclined to believe, or whether these liberated granules have not been actually gonidia. Probably the work done by *Prażmowski* (1912–1913) will prove most valuable as a basis for further investigations in this direction, as here the reproduction of new cells from the nuclear granules has been studied inside as well as outside of the parent cell. In addition some very suggestive work done with yeasts also deserves our attention. *Eisenschitz* (1895) collected valuable data concerning the staining qualities, motility, division, and arrangement of nuclear granules in yeast cells and about their participation in budding; and *Hest* (1907) contributed a highly interesting article on "pseudo-vacuoles" and "pseudo-nuclei" in yeasts, showing that the frequently mistaken "granules" in this case too acted clearly as reproductive organs, very much like the bacterial gonidia. Some of his drawings and photographs could be readily accepted as illustrating analogous processes in the life of Azotobacter.

The chromatin granules have usually attracted most of the attention of the various investigators, whose results, however, diverge widely, a fact not difficult to understand. With regard to the higher organisms the chromatin has been declared to be "the vehicle in which the constitutional structure, primarily of the species and secondarily of recent ancestors and parents is represented" (*Spencer*, 1898, p. 264). With the bacteria at least in the case of endospore formation the concentration of the chromatic substance has been always noticed, though especially in ripe old spores the presence of other substances may occasionally greatly affect the microchemical reactions, which fact, studied especially by *Zettnow* (1899), has misled some authors like *Růžička* (1913) to believe that the chromatin "vanishes" in old spores. Again, with regenerative bodies and gonidia the analogous change in stainability may occur, though it is generally less frequent than with endospores. Growing gonidia and regenerative bodies, however, will always, like growing endospores, exhibit the chromatin reactions very clearly. Thus far the chromatin granules present in the bacterial cell have been accepted by the various authors as being of very different physiological value, an opinion which is undoubtedly justified to some extent, but which at the present time is usually much more based on assumption than on evidence. This is particularly true in regard to such cases where the ever-ready hypothesis of "involution forms" has been invoked indiscriminately. *Beck* (1903, p. 777), for instance, does not hesitate to declare:

> So viel steht fest, dass die Differenzierung des Plasma des Bakteriums und damit auch die Bildung der chromatischen Substanz in demselben mit der Vermehrung und Fortpflanzung des Bacillus nichts zu tun hat.

But in the same "Handbuch," which contains this highly surprising statement, *Gotschlich* (1903, p. 83) connects the granules with an increased resistance of the cells and *Wladimiroff* (1903, p. 722) is certain about their reproductive character. *A. Fischer* (1897, p. 122; 1903, p. 8) classes them as reserve material; to *Migula* (1897, vol. I, p. 89) they are the beginning of nucleus formation. *Swellengrebel* (1907) saw round bodies of a "very complicated inner structure" develop in the center or at the end of the cell, but they, too, are to him "merely involution forms." *Petschenko* (1913) distinguishes those chromatin parts which are becoming "sporoids" (gonidia), from others participating in the metabolism of the cell, by the fact that the latter according to circumstances may increase and decrease in size, while the former show only an upgrowth, a fact evidently not easily to be ascertained and probably not always valid. Whether an observation made by *Bütschli* (1896, pp. 40–43) will be a helpful hint for recognizing growing gonidia, remains to be seen. This author noticed that the centrally located chromatin granules turned blue when stained with methylen blue, while those at the periphery, though reacting with Delafield's hematoxylin like those in the center, exhibited metachromatic qualities, becoming red with methylene blue. It is not impossible that there may be some relations between these findings and those recorded by *Thiercelin* (1903) concerning the "taches centrales" and "granulations périphériques," mentioned on p. 104, though it would be undoubtedly a serious mistake to assume that gonidia and regenerative bodies will always originate close to the cell wall; there is sufficient evidence on hand that at least the growing gonidia are often to be found in a central position and their diameter is not infrequently as large or even a little larger than the width of the parent cell.

The polar granules have been frequently looked upon as being enabled to assume a reproductive character, though the results obtained have been much at variance. So it has been the case with *B. typhi, coli, V. cholerae*, and *V. Finkler-Prior*, as may be seen, for instance, from the papers by *Ermengem* (1885), *Finkler* and *Prior* (1885), *Buchner* (1888), *Adami*, *Abbott* and *Nicholson* (1899), and by *Escherich* and *Pfaundler* (1903). That in the textbooks the polar granules are usually classed as "merely degenerative" or "simply artefacts" is in accordance with the generally prevailing practice; and it is, of course, indisputable that rough handling of dried smears may cause the appearance of plasma clumps looking like polar granules, but not having their physiological value, and, therefore, furnishing no proof whatever in regard to the meaning of those polar granules, which are present in the living cell. *N. K. Schultz* (1901 *a*) made some interesting observations concerning the reproductive function of the polar granules in old cells of the plague bacillus, as may be seen from her drawings reproduced as

figure 61 on Plate O (from original fig. II), illustrating the development of the polar granules to a uniformly distributed cell content. *Baur* (1905) has shown that polar granules participate in the formation of the arthrospores produced by Myxococcus; and that they are equally connected with the development of endospores has been frequently observed. Their independent acting as reproductive organs, however, remains to be studied more thoroughly, before any well-founded answer can be given.

The metachromatic granules, which *Babes* (1889) first found to be frequent with all kinds of bacteria, especially in older cultures, have been characterized in that paper, besides by their being stained violet by methylene blue, by their ability to reproduce new vegetative cells and by their acting in this direction as counterparts to endospores, though not exhibiting such an exceptional resistance against heat and drying. In a second paper (*Babes*, 1895) they were declared to participate in cell division, as well as in the formation of spores, buds, and branches; and in a third contribution (*Babes*, 1914) the so-called Much's granules of the tubercle bacillus were identified with them, and their rôle as reproductive organs was once more emphasized. To *A. Fischer* (1897) their metachromatic behavior was merely caused by the assumed fact that the accumulation of the stain within was said to prevent the passage of light, so that only the reddish reflex characterstic of methylene blue remained noticeable. *Guilliermond* (1910), who next to *Babes* studied the subject most intimately, contests this author's interpretation, as well as that preferred by *A. Meyer* (1903), who identifies the metachromatic granules with his so-called volutin. According to the French author, metachromatic granules are produced not only by all bacteria, but also by all protozoa, yeasts, other fungi, as well as by higher organisms; which statement leaves hardly any doubt, that, in fact, rather different objects have been grouped together. If, therefore, other authors like *Jordan* (1909, p. 58), *Frost* and *McCampbell* (1910), and *Dobell* (1911) assume that the metachromatic granules are some kind of reserve material, but do not participate in the life of the cell, though *Fedorowitsch* (1902) and *Fuhrmann* (1906) have demonstrated that growing gonidia, regenerative bodies, as well as spores, also exhibit, at least temporarily, metachromatic reactions, such conflicting statements are, indeed, not so irreconcilable as they may seem to be at the first moment. The large metachromatic globules, which *Hölling* saw in old spirilla cultures and which he interpreted as volutin, despite their ability to divide themselves, will also have to await a more correct classification. The same holds true concerning those metachromatic granules which were found in and outside of "Mastzellen" and were classed as metabolic products by *Bargum* (1903) as well as by *Guilliermond* and *Mawas* (1908). That some of them may be gonidia or regenerative bodies of bacteria is just as well possible as was the case, e. g., with the round bodies seen by *Hibler* in and outside of "Mastzellen" accompanying the bacilli of symptomatic anthrax, and also in the pure cultures of this organism, as was discussed on p. 67. *Ross* (1912) pointed out specifically that the large spherical bodies studded with chromatin granules, which are produced by spirochaets (as well as by other bacteria in their symplastic stage) can be easily mistaken for mast cells.

The granules first described by *P. Ernst* (1888), and usually called accordingly, have been often identified with *Babes'* metachromatic granules, for instance by *Bütschli* (1890), *A. Fischer* (1897), *Marx* and *Woithe* (1900), *Kamimura* (1903), *Bonazzi* (1915), and others, though their solubility in boiling water differentiates them from *Babes'* granules, whose relation to reproductive organs is certain, at least to some extent, as with the granular form of tuberculosis, mentioned above. When *Coppen-Jones* (1895) maintained that *Ernst's* granules be growing "spores" of the tubercle bacillus, he also evidently meant *Babes'* granules, and the great difference which exists between the claims made by *Marx* and *Woithe* (1900) concerning the rôle played by the "Babes–Ernst" granules in the life of pathogenic bacteria, and the results recorded by their opponents like *Ficker* (1903), is due undoubtedly to the study of different things, all included under the same conventional term. It is true that *P. Ernst* himself in his first paper (1888) dealt prominently with *B. xerosis* and its sporeformation, as studied by *A. Neisser*, and in his second paper (1889) he calls the inclusions directly "sporogenous granules," though evidently many of them, as described and illustrated in the paper, have nothing to do with the formation of spores or other reproductive organs; in a more recent paper (*P. Ernst*, 1902), too,

some of the bodies show again marks of having been gonidia (budding, fission, and motility after liberation). Nevertheless, it has become such a general practice to ascribe to "*Ernst's* granules" solubility in boiling water, since *Bunge* (*1895*) and *Mühlschlegel* (1898) have differentiated their "sporogenous" granules from them in this way, that it will be preferable to adhere to this practice, and to use this method for differentiating between soluble and insoluble metachromatic granules, and for obtaining eventually more information upon their relations to the various reproductive organs.

That the staining reaction not infrequently changes during the development of the gonidia and regenerative bodies, though usually not to such an extent as with the endospores, has been frequently noticed in the course of our studies. While usually well accessible to aqueous dyes especially to fuchsin, gonidia as well as regenerative bodies sometimes become hard to stain, a point which has been studied to some extent by *Kuntze* (1904) with regard to the gonidia ("Schwärmer") of *B. oxalaticus*. In most cases, however, the comparatively very dark color of the stained regenerative bodies is very conspicuous, as may be also seen from the photographs reproduced on several of our plates. In addition, aqueous fuchsin often causes a peculiar tint of red with regenerative bodies, which is well discernible after sufficient training of the eyes.

As no sharp microchemical differentiation is possible at present, and possibly never will be, between chromatin and metachromatic granules on the one side and growing reproductive organs on the other, so also fat, glycogen, and other so-called reserve material will be used in smaller or larger quantities by the bacterial cell for building up its reproductive organs, and, therefore, the more or less characteristic reactions of these substances will be also noticeable with growing gonidia, regenerative bodies, and spores. It would be, of course, a serious mistake to draw rashly final conclusions from such tests, and it should also be constantly borne in mind when making microchemical experiments with bacteria, that these reactions are by no means so prompt and reliable as one might be inclined to believe after having read, for instance, the books of *A. Meyer* (1903–1912). On the other hand, it would be equally unwise to share such an extreme standpoint as was taken by *A. Fischer* (1899), who felt compelled to fight against the "staining mania" ("Färbungstaumel"), mostly because he got all kinds of reactions and artefacts under conditions which were rather different from those prevailing in bacteriological tests. The following statement made by *Kruse* (1910, p. 48), however, may be accepted as fairly correct:

> Man traut . . . den meisten mikrochemischen Identifizierungsverfahren doch zuviel zu.

Fat has always taken the most prominent place among the substances used for "explaining" the presence of various granules within the bacterial cell. *R. Koch* (1876) was quite positive that the Anthrax spore be made up of a bright droplet of some kind of oil, covered by a thin protoplasmatic layer. And at present often a staining with sudan, etc., is considered to be sufficient evidence to establish the presence of "fat droplets" inside or outside of the cell, though it may have been gonidia containing some fat, but, of course, also all other substances necessary to a continuation of bacterial life. *Büsgen* (1894) felt completely justified to reject the findings of *Zopf* (1881) and *Billet* (1890) concerning the globular gonidia produced by *Cladothrix dichotoma*, because he was able to "solve" these "fat granules" by treating them with hot alcohol. In fact, however, he merely extracted some fat from what he calls a "vacuoliges Protoplasmagerüst," and the direct observations, made by the earlier authors upon the germination of these bodies, are, of course, also not eliminated by this extraction. The manner in which *Henneberg* (1901) classed as "fat droplets" what has been evidently the very conspicuous regenerative bodies of lactobacilli, was criticized on page 103. In publications of *P. Eisenberg* (1909) and *Vahle* (1909) the "fat" hypothesis plays an equally prominent rôle. *Kruse* (1910, p. 48), too, accepts the fat reactions as full proof that, e. g., the so-called sporogenous granules not only contain some fat, but that they are nothing else than "fat droplets." On the other hand, *Altmann* (1894, pp. 101–104) has already pointed out that the cell granules which participate actively in the cell life of the higher organisms may also assimilate considerable amounts of fat without reducing their vital activity even if

they appear micorochemically like large fat drops. With Blastomycetes, *Casagrandi* (1897) found out that such apparent fat granules react like nuclein and protein substances after the fat has been extracted by alcohol. The "swarming bodies" of *B. oxalaticus* have been tested by *Kuntze* (1904) also with the result, that they may contain, but that they are not, fat; and the same has been said concerning similar "sporoids" by *Růžička* (1909), *Vay* (1909), and *Ambrož* (1909), especially against *P. Eisenberg*. The protein reaction has been quite evident as far as tests have been made in this direction. That especially the granules of the tubercle bacilli contain albuminous together with fatty substances was ascertained by *Deyke* (1910) and confirmed by *Babes* (1914), who compares them also in this respect with the endospores of the bacilli.

Besides fat, according to *A. Meyer* and his pupils, volutin is to be credited with playing an important rôle as reserve material in the bacterial cell. The fact, however, that it is declared (*A. Meyer*, 1912, p. 204) to be absent in spore-forming bacilli, Pseudomonas, Streptococcus and Sarcina, does not support this view, and as this "volutin" admittedly belongs to the protein substances, more thorough tests of the so-called volutin globules especially in spirilla seem to be necessary; they bear a suspicious resemblance to those other globules which were found by some authors to be without any significance, while others have seen them germinate quite readily and grow up to new spirilla. *Dietrich* and *Liebermeister* (1902), as well as *Růžička* (1908), have already critized the volutin hypothesis. *Prażmowski* (1912, p. 157), too, calls this substance "highly problematical;" and *Minchin* (1915) is convinced,that the "infective granules" (i. e. gonidia) of trypanosomes (spirochaets) have been frequently mistaken as "volutin."

The "granules" and "globules," visible in and outside of the bacteria, have also been often readily accepted as glycogen, merely on account of the brown color sometimes exhibited by them when treated with iodine. That this reaction is by no means very stable has been frequently noticed. The round buds ("Aussprossungen") of *B. radicicola*, e. g., showed, according to *Hiltner* and *Störmer* (1903), often but not always glycogen reaction. The inflated forms of *B. Chauvoei* were found by *Hibler* (1908) to turn brown, violet, or yellow. Similar inconsistencies have been discussed by *Prażmowski* (1912, p. 158) with regard to Azotobacter. *Kuntze* (1904) noticed that the swarming bodies of *B. oxalaticus* turned yellow at the outside, brown in the center. To assume that bodies exhibiting the glycogen reaction be nothing else than glycogen, would be equally erroneous as to class them as "merely fat droplets," because they behave in a similar manner.

Mencl (1910) preferred to interpret the brown color, caused by iodine in buds of Azotobacter, as indicating amyloid, and rejected the assumption that they are plasmatic substances.

The coccoid bodies of sulphur bacteria, whose motility and multiplication had been studied by *Zopf*, were claimed by *Winogradsky* (1888) to be nothing else than "sulphur granules," an assertion which has been sufficiently answered by *Zopf* (1895). Concerning the blastia of *Perty* (1852), *Migula* (1897, Vol. I, p. 8) made an analogous, equally unfounded statement.

The "Schwebekörper" or "Aërosomen," attributed by *Molisch* (1907) to Rhodobacteria and Phycochromaceae, will also have to await renewed critical study.

The astonishing properties of the "vacuoles," discovered by *Zettnow* (1896–1897) inside, as well as outside, of various spirilla, have been mentioned on page 99; and the interesting interpretation given by *Hest* (1907) in regard to the "pseudo-vacuoles" of yeast cells, was quoted on page 109. *A. Fischer* (1903, p. 7) was of the opinion that deeply staining inclusions in spirilla were to be explained as vacuoles, wherein the stain became accumulated, while other investigators usually have interpreted those parts of the body to be vacuoles, which were only weakly stained or not at all.

Some special rôle in oxydative processes going on in the cell has been attributed to granules present within the bacterial cells by *Dietrich* and *Liebermeister* (1902), as well as by *Brandt* (1913). If this hypothesis should be correct, the fact itself would not militate against an eventual participating of such granules in the processes of multiplication and reproduction.

All cell inclusions mentioned above, part of which will undoubtedly be recognized as identical with gonidia or with regenerative bodies, when thoroughly studied, have been classed as the result of either the normal or the abnormal metabolism of the cell. The "fatty degeneration" especially plays a conspicuous rôle with many authors, despite the rather insufficient basis on which this hypothesis rests. There are numerous other cases, however, where it also has been considered to be quite sufficient, simply to state that the objects seen were "merely involution forms," and to abandon all further research upon them. With regard to the vegetative cells it has been shown in the first chapter (pp. 24–29) to what extent this term has been misused very frequently, so that it is not necessary to dwell upon this point once more. Only this may be emphasized again, that among the reproductive organs the endospores most clearly display all marks of true involution, but they hardly ever have been classed as such. They too show, however, that as in many other cases, so also here, involution may be followed by evolution, and the same holds true for bacterial reproductive organs generally. That, for instance, the sporoid bodies in vibrios and spirilla should not be laid aside as "involution forms," as was done by *Doyen* (1885) and others, has been pointed out by *Weibel* as early as in 1888. He says directly:

> Es bedarf fast einer gewissen Selbstüberwindung, sie als Sporen zu verleugnen.

That the exceptional resistance, often, though not always, exhibited by endospores, is not to be found with the other reproductive organs, has evidently also caused some misunderstanding. *Woodhead* (1891), for instance, makes the following remark concerning the so-called arthrospores of the cholera bacillus, notwithstanding their ability to germinate:

> As any apparent spores that have been formed invariably failed to resist the action of drying, such "arthrospores" containing bacilli must, for the present, be looked upon as involution forms.

The same standpoint was taken more recently by *Hiss* and *Zinsser* (1914, p. 16), as well as by *Kendall* (1916, p. 30). *Wertheim* (1899), who first observed the breaking up of the Gonococcus into minute coccoid bodies, was careful enough to test their further behavior and was able, therefore, to find out that also in this case the "involution" was followed by a new evolution of typical cocci. *Swellengrebel* (1907), on the other hand, classed and discarded the round bodies within spirochaets as "involution forms," though he saw them growing and noticed their "very complicated inner structure," both undoubtedly no marks of degeneration. With regard to the "conidia" (i. e., gonidia and regenerative bodies) described by *Almquist*, *Gotschlich* (1909) made the unique remark that they can not be accepted as reproductive organs, because they do not have "einen bestimmten, streng eingehaltenen morphologischen Character"; an interesting proof to what extremes an author may be misled by strict adherence to the monomorphistic doctrine. That the German author, in fact, erred in making this statement, is sufficiently proven by an inspection of *Almquist's* drawings, reproduced as figure 54 on Plate N, and of his photographs, to be found on Plate XI as figures 135–139. The form of these reproductive organs is at least as distinct as that of the vegetative cells, and it has been emphasized already that especially the round regenerative bodies of very different species may assume a vexatiously uniform appearance. But even if *Gotschlich's* claim would be right, his remark would still have to be rejected, because the true character of a reproductive organ is always determined by its physiological behavior, viz., by its ability to reproduce vegetive cells, but never by its morphology.

The term "granular decomposition" has been often used as affording another chance to bring bacteriological researches to an early end. The process was described by *Hueppe* (1886, p. 108) as "retrograde metamorphosis"; the granules were declared by him to be entirely unable to enter on a new development, and it was pointed out by him specifically that they should not be put parallel to gonidia. Less dogmatic, but more correct, *Cornil* and *Babes* wrote in their textbook (1890, Vol. I, p. 33):

> On peut constater, à un moment donné dans la chambre humide, que des bactéries de diverses espèces se transforment en granulations qui resemblent à des microbes ronds. Mais souvent ces granulations ne sont plus vivantes ni inoculables.

The experiments made by *Pfeiffer* (1894) and by *Pfeiffer* and *Kolle* (1896) upon the granular decomposition of cholera and typhoid bacilli in immunized guinea pigs, as well as those of *Emmerich* and *Saida* (1900) upon the analogous behavior of anthrax bacilli, when treated with pyocyanase, have especially created the widespread belief that all "granular decomposition" without exception be indicative of the death of the bacteria. However, already in 1898 *Cantacuzène* pointed out that the granules in *Pfeiffer's* experiment are, at least sometimes, living and able to propagate; and he also discovered the interesting fact that only living, not dead, organisms showed this kind of transformation. Bacilli killed by heating were still agglutinated within the animal, but were otherwise unchanged after 3–4 hours. *Kohlbrugge* (1901 *a*) noticed that hemoglobin stimulated the granular transformation of *V. cholerae*, and he also observed the reproduction of regular bacilli from these granules. *Gotschlich* (1903, p. 58), too, admits—

dass die sonderbaren körnigen Degenerationsproducte der Cholerabacillen beim Pfeifferschen Phänomen, sowie der Pestbacillen in Bubonen . . . eine Zeit lang ihre Lebens- und Regenerationsfähigkeiten in Kulturen behalten.

That the same may not only happen in cultures but also in the organism, was indicated by an observation made by *Nakayama* (1906) in animal tests with Actinomyces asteroides, where a new growth of threads started from the granular detritus within the phagocyts. *Much* (1909) emphasizes with regard to the dissolution of bacteria within the leucocyts:

Auflösung ist nicht gleichbedeutend mit Abtötung . . . Bringt man Pneumokokken mit einem agglutinierenden Serum in Berührung, so quellen sie auf und verlieren volkommen ihre Färbbarkeit. Trotzdem sind sie aber nicht abgetötet.

The breaking up of *Spirochaeta gallinarum* into granules, when kept in fowl's blood, is another instance where granular decomposition does not mean that life is at its end. According to investigations made by *Hindle* (1911) and others, these granules are undoubtedly reproductive organs, though *Swellengrebel* (1912) tried to apply the volutin hypothesis in this case, too.

A very thorough discussion of the whole subject has been published by *Herzog* (1913), who once more confirmed that "granular decomposition" and "partial bacteriolysis" of gonococci, plague, cholera, hog cholera, and other pathogenic bacilli within the body is by no means always equivalent to their ultimate destruction; the granules are eventually able to reproduce a new generation of typical bacteria. It may be added that *Simonini's* (1914–15) studies upon the influence of certain elements (lantham, cer, thorium) upon *B. coli, typhi, dysenteriae, cholerae, subtilis, anthracis, diphtheriae*, meningococci, gonococci, etc., have also furnished several interesting details, which may become helpful for further work upon the meaning of this "granular decomposition." Here the granules once more have proved themselves to be able to act as reproductive organs, though the process of regeneration was often greatly delayed, and not infrequently such properties as virulence, motility, gelatine liquefaction, were absent for a long time in the new cultures, developed from the granules.

Closely related to the facts just mentioned are other observations like those recorded in 1881 by *Fokker* and in 1883 by *Archangelski* concerning the temporary replacement of anthrax bacilli by coccoid bodies within the organism. *Vignal* (1889) noticed that in artificial cultures, too, and already from the second day on, some of the rods of *B. mesentericus* began to contract their plasmatic content into similar granules, leaving vacuoles in the cells, which fact was interpreted by the French author as follows:

Il est impossible d'attribuer cet état à un appauvrissement du milieu nutritif ou à la formation de matières nuisibles, car à côté des bacilles vacuolisés on en trouve d'autres qui se divisent énergiquement.

Many authors, however, were only too willing to declare a priori any formation of granules to be degenerative, while only few were inclined to admit that degeneration might be followed by regeneration and both processes are part of the normal life cycles of the bacteria.

The following remark made by *Chester* (1901, p. 14) with regard to the granules in Mycobacteria, which he already correctly classed as gonidia, holds true for many analogous cases:

Certain bacteriologists have considered many of these so-called gonidia as degeneration forms; but it is more likely that they are distinct morphologic elements, inasmuch as degenerative elements could not be expected to produce new vegetative cells.

On the other hand, it was a fundamental mistake when *Wladimiroff* (1903 *b*) declared the granules in spirochaets to be merely degenerative, "because" they are not resistant against heating. *Gotschlich* (1903, p. 43), *Kruse* (1910, p. 31), as well as *Lehmann* and *Neumann* (1912, p. 517), also classify this granula formation as "degeneration," though they admit at least the possibility of a succeeding regeneration.

The terms "segmentation" and "fragmentation" have been used occasionally, especially in regard to the formation of arthrospores by Actinomycetes. *Kruse* (1896 *a*, p. 55) wanted to have both terms sharply separated:

> Nicht zu verwechseln mit der Segmentierung, durch welche lebensfähige, normale Elemente geschaffen werden, ist der unregelmässige Zerfall von kürzeren und längeren Bakterienzellen in ungleiche und oft abnorm gebildete Teilstücke, die Fragmentierung, die in alten Kulturen zu beobachten ist.

But he defined himself the fragmentation in the following manner:

> Es ist das offenbar ein regressiver Vorgang, der hier nur erwähnt sein mag, weil die Möglichkeit nicht ausgeschlossen werden kann, dass unter günstigen Umständen aus dem Zerfall noch lebensfähige Keime hervorgehen, die sich durch eine Art von Verjüngungsprozess . . . zu normalen Elementen regenerieren können.

Both processes, therefore, are reproductive; and already *Zopf* (1883, pp. 10–12) has described the fragmentation of bacteria as "some kind of propagation," placing it parallel to the production of the so-called hormogonia by fission-algae. Accordingly, both terms have been used in the bacteriological literature, especially in papers on Actinomycetes, practically synonymously, as may be seen from the publications by *Lachner-Sandoval* (1898), *Neukirch* (1902), *Gilbert* (1904), *Lepeschkin* (1904), *Haas* (1905), *Schütze* (1908), and *Lehmann* and *Neumann* (1912, p. 623).

Růžička (1907) has correctly emphasized that the regeneration of normal bacteria from living fragments has so far not met with adequate attention, despite the important rôle played by the analogous process in the life of other primitive plants and animals.

In the same manner as the terms "degeneration," "involution," "reserve material" or other "cell inclusions" had to serve undoubtedly much too frequently for "explaining" the observations made upon various types of reproductive organs and for uniting them with the rigid monomorphistic doctrine, which allowed only one constant form of the vegetative cell and only one mode of reproductive organ, the endospore, as studied by *R. Koch* and his pupils, so also the genuine or merely hypothetical artefacts have been often invoked to allow a quick discarding of unexpected facts.

Among the so-called artefacts those introduced by *A. Fischer* (1891, 1900) as being the products of plasmolysis and plasmoptysis have been widely accepted by bacteriologists as really important facts. Though *A. Fischer's* claims were supported by only very little and obviously unsatisfactory experimental work, and though only very few confirmative, but many contradictory, results have been recorded since then, especially the plasmoptysis, characterized by *A. Meyer* already in 1905 as an "outgrowth of *A. Fischer's* vivid imagination," is still treated by writers of bacteriological textbooks as a very important fact. There is no doubt, of course, that bacteria like other cells may be induced by a hyperosmotic environment to contract their cell plasma, i. e. to exhibit so-called plasmolysis; and it is equally beyond question, that a sudden change from high to low pressure may cause an increase of the inner tension to such an extent, that the cell wall breaks and part of the content is forced out with more or less vigor. *A Fischer* (1900) himself, however, has practically eliminated this osmotic basis of his theory by reporting first that plasmoptysis may occur with some but not with all cells, when they are transferred from a low to a high concentration, and, second, that plasmolysis and plasmoptysis may occur simultaneously in the same single cell (*A. Fischer*, 1900, p. 10). Accordingly, *Kolle* and *Hetsch* (1911, p. 30) readily accept both terms as correct explanations of all kinds of processes going on in cultures, as well as in the organism, which they consider to be degenerative, and state explicitly:

> Die Ursachen der Plasmoptyse und Plasmolyse können sehr verschiedenartig sein . . . Es ist daher nicht erlaubt, aus dem Vorgang selbst Schlüsse auf das auslösende Agens zu ziehen.

If every plasma contraction should be called plasmolysis, then naturally all gonidia formation would have to be identified with it, but as the term can be used correctly only in those cases where, in fact, the change in osmotic pressure acts as causative agent, gonidia formation may occasionally be mistaken for plasmolysis, especially if the last-named authors' advice should be accepted, but more careful research will always reveal the inherent difference between both processes. *Podwyssotzky* and *Taranoukhine* (1898) went even so far as to link the spore formation of *B. anthracis* with *A. Fischer's* plasmolysis theory, though this species, like several other spore-forming bacilli, was declared by *A. Fischer* (1903, p. 25) to be not subject to plasmolysis on account of its permeability. As many other species (sarcinae, streptococci, staphylococci, etc.) were also found by the same author to be not inclined to show any plasmolytic reaction, this process unquestionably can not be used as a correct explanation for the formation of those granules by all bacteria, which, though contracted plasma, demonstrate by their further behavior that they are actually reproductive organs.

That genuine plasmoptysis has still less to do with the production of reproductive organs than has plasmolysis, is equally evident. *A. Fischer* never furnished photographic pictures of what he saw in his experiments; the drawing reproduced as figure 62 on Plate O from his textbook (1903, original fig. 27) is obviously highly schematized and is rather different from the drawings given in another paper (1906), one of which has been reproduced as figure 181 on Plate XV (from original fig. 8 on Pl. III). This ejecting and dissolving of irregular clumps of plasma is, indeed, what might be expected, and is also in accordance with the original description given by *Fischer* (1900), while all his other data concerning the formation of a new membrane around the ejected plasma and the motility of these bodies, evoke a strong suspicion, that he actually has had side by side in his preparates plasmoptysis, as well as gonidia and regenerative bodies, and that indiscriminate "explaining" of the latter fact by the former has caused the development of his incorrect theory. Furthermore, it has to be remembered, that many of the globules, considered by *A. Fischer* to be "Plasmoptyse-Kugeln," have been merely droplets of some organic substances ("dirt droplets," as *A. Meyer* called them), which are indeed quite common with coverglasses which have not been thoroughly cleaned. *Leuchs* (1905) has directed the attention to this fact, which has been admitted by *A. Fischer* (1906). Additional data concerning genuine and so-called plasmoptysis were furnished by *Blau* (1905), *A. Meyer* (1905–1906), *Hammerl* (1906) and *Garbowski* (1906–1907). The last-named author, though working in *A. Fischer's* own laboratory, was equally unable to confirm this authors statements. A fairly pronounced plasmoptysis was recorded only by *Schuster* (1910), who cultivated some bacteria in a 10 per cent ammonium sulphate solution. Under normal conditions plasmoptysis is of no importance whatever; a study of the slow growth of budding gonidia and regenerative bodies will, as *Meirowsky* (1914) has emphasized, at once demonstrate that these organs are by no means the result of a sudden osmotic eruption, and their further behavior confirms this fact.

The occurrence of artefacts in stained preparations is a point which needs constant attention in all investigations upon gonidia and regenerative bodies. Very deceptive artefacts may be obtained occasionally with nutrient solutions containing albuminous or fatty substances or with certain staining methods; but it would be wrong, of course, to conclude from such happenings that the same artefacts are also present in other cases. Important information in this respect may be derived from *A. Fischer's* book entitled "Fixierung, Färbung and Bau des Protoplasmas" (1899), though again the conclusions drawn by the author are often out of all proportion to their experimental basis. *Weibel* (1888), who was among the first to study formation and development of bacterial regenerative bodies, has already selected the one way which avoids the disturbing influence of artefacts in stained preparations, viz., the examination of the living organism in the hanging drop. That vital staining with methylen blue may be helpful, was shown by *Zettnow* (1897), *Nakanishi* (1900*a*), *Růžička* (1903), *Meirowsky* (1914*b*), and others. Absolutely clean coverglasses are, of course, equally important in this case, as they are in regard to "plasmoptysis."

A particularly disturbing effect may be caused occasionally, as was pointed out in our second preliminary report (*Löhnis* and *Smith*, 1916*b*), by the fact that many of the thick walled regenerative bodies are killed, but not dissolved by thorough heating of the substrates. Therefore, it may and will happen, especially with substrates containing pepton or other ingredients which were exposed to strong bacterial infection, that dead foreign bodies are present in perfectly prepared and sterilized media, which may enter the field, well stained and evidently being genuine regenerative bodies, though actually representing an unwelcome contamination. The use of various substrates, kept in thoroughly cleaned vessels, will usually suffice to eliminate this possible cause of error, though occasionally filtering of the medium through a reliable bacteria filter will become necessary to secure definite results.

Granules in blood and tissue may be easily mistaken for reproductive organs of bacteria and vice versa. The granules in "Mastzellen" have been discussed on p. 111. That those in liver and other tissue may be bacterial gonidia has been mentioned repeatedly (see e. g. *Bordoni-Uffreduzzi*, p. 97, and *M. E. Abbott*, p. 103). The production of "infective granules" by spirochaets has directed the attention of bacteriologists to the hemoconia and other granules in blood. As early as in 1880 *M. Wolff* and *Guttmann* have dwelled upon this subject, which has been more recently discussed by *Rabinowitsch* (1909), *Balfour* (1911*c* and 1912), *Gleitsmann* (1913), *Herzog* (1913), and by *King*, *Baeslack* and *Hoffmann* (1913). As with blood, the dark field method may also cause considerable trouble when used in other cases; comparative examinations of the sterile media are necessary to avoid mistakes due to the presence of other granules in the substrates.

Cienkowski already emphasized in 1877 that the direct observation of the development of gonidia to bacteria is the only final proof that these small round bodies are not merely cell inclusions, but actually reproductive organs. *Zopf* (1879), *Toussaint* (1884), and other early authors took the same standpoint, which, of course, is beyond dispute.

But *Zopf* (1895) was also right when he refuted *Winogradsky's* exaggerations concerning the identity of gonidia with "sulphur granules" on the ground that he had seen them multiply as such, though they did not revert in his experiments into the original rods and threads. At the present time, where so little is known upon the conditions favoring the upgrowth of gonidia and regenerative bodies to fully developed bacteria, it will have to be considered to be, indeed, quite satisfactory, if only the formation and the multiplication of these reproductive organs as such can be directly followed. *Adami*, *Abbott*, and *Nicholson* (1899), for instance, were not always able to get a regular upgrowth from the gonidia of *B. coli;* sometimes they reverted promptly, in other cases they merely multiplied. A culture of motile "cocci" (gonidia), isolated by *Stamm* (1914) from *V. cholerae*, which was shown in figure 82 on Plate VII, grew as such in 65 transfers during 7 months, then it reproduced again large curved forms. Similar results will have to be expected frequently, but they can at least be accepted as decisive answer in regard to the various problems concerning artefacts, reserve material, etc., though, of course, the possibility of a contamination by cocci has also to be kept in mind. This point, however, can be eliminated without great difficulty. Microscopically, as well as macroscopically, the growth of gonidia and regenerative bodies is so different from that of micrococci, that a somewhat experienced investigator will not be led astray.

The situation is much less satisfactory if the problematic bodies refuse to grow under the conditions selected for the experiments. Such negative findings have been recorded, e. g., by *Růžička* (1907), *Fontes* (1910), *Leishman* (1910), *Th. Smith* (1913), *Wolbach* (1915), and many others. *Leishman* and *Smith*, however, though failing in the cultural experiment, succeeded in the animal test, and there is no doubt that as our knowledge will increase also cultural experiments will become more and more successful. To specify the conditions beforehand and, if they prove to be not suitable, to draw from such a negative result the final conclusion that no growth is possible, is, of course, a very serious, though unfortunately not infrequent, mistake. *Miehe* (1913), for instance, was absolutely certain that the globular forms produced by his *B. repens* were "merely involution forms," because they did not germinate in his hanging drop. But the normal rods of *B. foliicola*, which he also studied in the hanging

drop, were equally not inclined to grow and to multiply under his eyes; yet there is nothing said about their being "merely involution forms." With endospores the irregularities in germination are well known, and in this case a negative finding will never be accepted as decisive. Exactly the same standpoint has to be taken in regard to the other reproductive organs of the bacteria.

The motility often shown by the gonidia, and sometimes by regenerative bodies, as well, may be accepted as a fairly conclusive proof, though the Brownian movement of small foreign bodies, especially conspicuous in the dark field, makes "eternal vigilance" imperative. The use of antiseptic substances was found to be helpful by *Kuntze* (1904). The staining of flagella is still more conclusive, but, of course, also much more difficult. The photographs reproduced as figures 160 and 161 on Plate XII, show clearly that satisfactory pictures of these minute details are not easily obtainable. One long flagellum seems to be very common with the motile gonidia of practically all groups of bacteria. It has been so recorded by *Giard* (1882) for *Crenothrix*, by *Beijerinck* (1888) for *B. radicicola*, by *Plaut* (1907) for *B. fusiformis*, by *D. H. Jones* (1913) for *Azotobacter*, by *Marrassini* (1913) for *B. subtilis*, and by *Stamm* (1914) for *V. cholerae*. As is the case with the motility of the bacilli themselves, so also the motility of these reproductive organs may vary according to circumstances. According to *Migula* (1897, Vol. I, pp. 202–205) the gonidia of Crenothrix are immotile, while others saw motility, and Cladothrix gave him immotile as well as motile gonidia. *Adami* and his collaborators (1899) found those of *B. coli* immotile, while *Kellerman* and *Scales* (1916) noticed a very conspicuous motility. The gonidia and regenerative bodies of *V. cholerae*, which practically always exhibit a lively motility, as was seen by *Hammerl* (1906), *Kolle* and *Hetsch* (1911), *Stamm* (1914), and others, may show variation, too; *Almquist* (1908) found them to be motile at 20° C., immotile at 10° C.

(c) THE DIFFERENT TYPES OF REPRODUCTIVE ORGANS.

It goes without saying that a sharp distinction between the different types of reproductive organs is not possible in every case. They all serve the same fundamental purpose: cell reproduction; but in addition they may either participate in multiplication, or they may act as more or less resistant resting forms, or they may combine these two supplementary functions. Their formation, development, and character will differ accordingly, but some overlapping will also be noticeable. Minute spots of nuclear material represent the beginning of all reproductive organs; the addition of plasmatic substances, of reserve material, and of a more or less resistant membrane determine their final appearance; but though this will suffice for making a correct classification in most cases, sometimes a close study of the actual development of the bodies concerned will be necessary to distinguish correctly, for instance, between regenerative body, arthrospore, and microcyst, or between endo- and exospore.

The names used by us at present for the four groups of reproductive organs are:

(1) Gonidia.
(2) Regenerative bodies and exospores.
(3) Endospores.
(4) Arthrospores and microcysts.

The meaning of these terms, and why they have been selected, may be discussed first; the literature relating to character and behavior of the different types of reproductive organs will be reviewed afterwards.

What we call gonidia of the bacteria is probably identical, at least partially, with what has been called eggs ("Eier") of the bacteria by *Ehrenberg* (1838); some of his observations, however, may also relate to endospores, and the name itself would be, of course, unacceptable now. The term "blastia" used by *Perty* (1852) is much better, but its original meaning has also been too broad. The endospores have been kept separate by the Swiss author, but besides the bacterial gonidia, his blastia also enclose regenerative bodies of the bacteria and various reproductive organs of protozoa. The "micro-gonidia," which *Karsten* (1869) observed to grow up to bacteria, have been probably also gonidia, as well as regenerative bodies. In relation to Crenothrix *F. Cohn* (1870) made use of the terms micro- and macro-gonidia, though he

admitted that no sharp distinction between both can be made. According to our present arrangement his macro-gonidia would have to be classed among regenerative bodies or microcysts. What *Sachs* (1875) named swarm-spores or zoospores of lower algae is equivalent to our gonidia of the bacteria; he calls them also micro- and macro-gonidia. In *Zopf's* paper on Crenothrix (1879) the terms gonidia and spores are used synonymously. According to *Béchamp's* description (1883) some of his "microzymas" are undoubtedly identical with the bacterial gonidia, but it is equally obvious that many other things, even part of the bacteria themselves, would be covered by the same name. Much of what should have been termed gonidia, has been called "cocci" by *Zopf* (1883); an inaccuracy which has been justly criticized by *Hueppe* (1886). Unfortunately, this author erred by asserting that gonidia be resting forms and unable to multiply as such, the latter fact being characteristic for cocci. If this would be true, *Zopf*, not *Hueppe*, would have been right.

The application of the term gonidia to the club-shaped cells of Actinomyces and of other organisms, as was done by *Bollinger* (1877) and by *A. Neisser* (1888), can also not be accepted as correct. These cells may contain gonidia, but they are not gonidia (i. e., seed) themselves. What *Klebs* (1887) called "microsomes" of the bacteria have been evidently true gonidia, and this term might be used had it not been applied by other writers, e. g., by *Spencer* (1898, p. 253), in a much more general sense to all plasmatic granules to be found in the cells. The motile gonidia of *B. radicicola* have been called zoospores by *Atkinson* (1893) and by *Hartleb* (1900). *Thiercelin* (1903) chose the designation "microblastes" for the gonidia of his Enterococcus. The so-called spores of *Spirillum endoparagogicum* (*Sorokin*, 1887), *Actinomyces bovis* (*Bostroem*, 1890), *B. coli* and *typhi* (*Almquist*, 1893), *B. fusiformis* (*Tunnicliff*, 1906), and of *Leptothrix* (*Chlamydothrix*) *ochracea* (*Petschenko*, 1916) exhibit all marks of genuine gonidia. Those produced by the trichobacteria have been called by *Migula* first (1900) conidia, later (1904) gonidia. *Ellis* (1907) and *Benecke* (1912) also wrote upon "conidia" in trichobacteria, while *Chester* (1901), *Schmidt* and *Weis* (1902), as well as *Frost* and *McCampbell* (1910), gave preference to the term "gonidia." The so-called conidia of *Almquist* (1904–1917) include gonidia as well as regenerative bodies. Whether the "sporoids" of *Růžička* (1909) have been gonidia must be left undecided. What *Jones* (1913) described as "gonidia spores" of Azotobacter, however, have been undoubtedly true motile gonidia. The expression "infective granule," used by *Balfour* (1911–1913) and others in relation to the gonidia of spirochaets, as well as other protozoological terms, like "marginal points," "anaplasma," are evidently not preferable to the old, fairly well established and defined term "gonidia." The terms blastia, microblasts, etc., I believe, do not deserve preference. As not all gonidia are motile, the use of the name zoospores can also not be recommended. And the rather indefinite expression "spores" should certainly be avoided. That "gonidia" (derived from γόνος = offspring) should not be associated with or replaced by "conidia" (derived from κονία = dust) needs hardly to be emphasized. Conidia are, according to *Lindau* (1904, p. 191):

> Sporen, welche exogen, d. h. ausserhalb der Zelle durch Abschnürung entstehen.

And:

> Die Konidien sind die recht eigentlichen Fortpflanzungszellen des Pilzreiches, denn sie zeigen die Anpas ung der Pilze an das Landleben in der höchsten Form.

It is true that under abnormal conditions conidia may be also formed internally, as has been described, for instance, by *Klöcker* and *Schiönning* (1899) for *Dematium pullulans* and other fungi, and one might say that the arthrospores produced by Actinomyces at its aerial hyphae are genuine conidia and the gonidia formed within its cells are such abnormal endogenous conidia. However, it seems to be much more preferable and recommendable to avoid, as far as bacteria are concerned, the term conidia entirely and to speak alone of gonidia. With the trichobacteria the latter term has been applied by some authors also to full-grown cells, when these are formed within the sheath, an extension of its original meaning, which better will be avoided as far as possible.

According to the old definition, given by *Sachs* (1875, p. 211) with regard to the lower algae, which, however, is equally applicable to the bacteria, gonidia are organs of asexual repro-

duction, formed by the contraction of the plasmatic cell content, which leave the parent cell either by breaking the cell wall, or which become liberated when the cell dissolves. Motility is frequently, though not generally, noticeable with bacterial gonidia. Usually two, four, or more gonidia are formed within the same cell. Their resistance, as a rule, is not very different from that of the full-grown, vegetative cell, as they are serving much more for multiplication than for preserving the life under unsuitable circumstances. They often seem to be made up nearly exclusively of chromatin substances; occasionally, however, the presence of reserve material (fat, starch, glycogen, etc.) may become so conspicuous that errors in the microchemical analysis may be caused.

As was mentioned above, the so-called infective granules, marginal points, etc., of protozoa are very similar to bacterial gonidia. What *Minchin* (1915) said in regard to protozoa holds also true in our case:

> Infective granules are true endogenous chromidial buds.

And:

> Each bud, when complete, has the morphological and cytological value of a true cell, very minute in size and reduced almost entirely to its chromatin elements.

That the bacterial gonidia sometimes may multiply as such for a long time before they revert to normal cells is in good agreement with this view.

Sometimes the endogenous production of gonidia assumes such proportions that a considerable increase in size and an alteration in the shape of the parent cell becomes visible. *Toussaint* called such cells "sporangia" (according to *Magnin* and *Sternberg*, 1884, p. 150) or "pseudothèques" (according to *Rodet*, 1894, p. 117). *Finkler* and *Prior* called them first "Ammen" (1884), later "Keulen" (1885). *Artigalas* (1885) spoke of "spores" containing "sporules," and *Carpano* (1913) also used the term "spores." That the latter term should not be applied in this manner is beyond question. But the names used by *Finkler* and *Prior*, as well as by *Toussaint*, are equally not acceptable. Therefore, it seems best to introduce the term "gonidangium," already used in mycology, but to reserve it for those "giant cells" producing numerous gonidia, and not to apply it to normal cells containing a few gonidia, though this, of course, would be etymologically equally correct. As will be seen, very many of the so-called involution forms of spherical, pear, and club shape are, in fact, gonidangia.

What we now call "regenerative bodies" is a collection of different reproductive organs whose proper separation and classification must be left for the time when more data will be available. Among the reproductive organs as described by earlier authors the following may have been regenerative bodies: Some of the macro-gonidia of *F. Cohn* (1870), the "arthrospores" of *V. cholerae* as described by *Hueppe* (1885), the round reproductive organs of Actinomyces growing singly on short side branches, which were called "chlamydospores" by *Schürmayer* (1900), some of the "bacteroids" of the nodule organism and of other bacteria, the "zygospores" of *B. radicicola* studied by *Hartleb* (1900), the "zygo- or stylo-spores" of *B. tuberculosis* described by *Droba* (1901), the "Dauerkapseln" of *B. tuberculosis* mentioned by *Schroen* (1904), part of the "conidia" of *Almquist* (1904–1917), probably some of the "unreife Sporenanlagen" frequently found by *Grassberger* (1903) with anaerobic bacilli, and the "Regenerationsformen" of Azotobacter discovered by *Prazmowski* (1912, p. 145).

Generally the regenerative bodies are characterized by their being easily and deeply stained by aqueous dyes, by their different appearance as compared with the vegetative cells (globular, oval, or irregular), by their ability to reproduce normal cells immediately or after having propagated as such by fission or by budding, by their distinctly increased resistance against drying, heat, or other detrimental influences. But, as has been said above, this grouping can be only accepted as some temporary arrangement, which will have to be discarded as soon as the different components of this group will be more completely known.

Some of them are evidently related to what we call terminal exospores and probably will later have to be united with them. Others seem to be genuine zygospores, as will be discussed more fully in Chapter IV. Many of the round forms, as well as some of those of irregular shape, usually characterized by an especially solid appearance, are produced directly

from the symplasm, as will be demonstrated in Chapter III. Perhaps the name "sclerotia" might recommend itself for the latter forms. But all final action upon this point, as well as the proper naming of the remaining "regenerative bodies," must be left to future experimental investigations.

"Exospores" are those reproductive organs which are produced either terminally or laterally and whose staining reaction and resistance are similar to those of the endospores. As to their mode of being formed, it seems not improbable, that they, too, are zygospores, and perhaps this will be their final denomination.

At present it is customary to call the "endospores" of the bacteria simply "spores", but this custom will have to be abandoned, as it is beyond doubt, that other bacterial reproductive organs are equally true "spores." The demand of some authors, like *Gamaleia* (1888), *Bruns* (1895), *Hawthorn* (1903), *Mertens* (1903), *Frost* and *McCampbell* (1910), that only those reproductive organs should be called spores, which are characterized by their special staining reaction and their exceptional heat resistance, can not be accepted as being correct. Σπορὰ means "seed," and therefore even the gonidia might be called spores, as has been done, indeed, by several authors. But as their morphological, as well as their physiological, character is so widely different from that of the typical spores, undoubtedly a special name was preferable in that case. On the other hand, it seems not to be justified to confine this term strictly to only one type of reproductive organs, and to exclude all others, which according to formation, development and general character, are very similar to them, though not quite so resistant to staining and heating. The use of the distinct term "endospore," therefore, is to be recommended; the term "cyst," as used by *Gamaleia* (1900), on the other hand, should not find application in this case.

The term "arthrospore," introduced by *Caspary* into the mycological literature, has been refuted by *Bail* as early as in 1857 on the ground that only those reproductive organs should be called spores which are the results of some process of fructification. The opposition was still more pronounced after *De Bary* (1884) had taken up this term for bacterial reproductive organs and *Hueppe* (1886), as well as *De Toni* and *Trevisan* (1889), had accepted and extended its use. *Kruse* (1896 *a*, p. 60), *Migula* (1897, Vol. I, pp. 37, 168; 1900, p. 8; 1904, p. 123), *Schmidt* and *Weis* (1902, p. 58), *A. Fischer* (1903, p. 42), *Gotschlich* (1903, pp. 82, 83), *Muir* and *Ritchie* (1903, p. 8), *Günther* (1906, p.21), as well as *Hiss* and *Zinsser* (1914, p.16), have all taken a more or less pronounced stand against this theory. However, a careful study of all reports concerned leaves no doubt, that the special morphology, increased resistance, and the germination of these spores have been fully ascertained at least in some cases, and, therefore, it is not admissible to discard them lightly as being "simply involution forms," as was done repeatedly. The term has been fairly correctly used by *G. M. Sternberg* (1893, p. 17), *Crookshank* (1896, p. 19), *Lafar* (1897, p. 62), *Gamaleia* (1900, p. 17), and *Benecke* (1912, p. 179), though all these authors paid more attention to those cases, where the whole vegetative cell was transformed, than to the others, where by a preliminary segmentation joints were formed which then became arthrospores. In our first preliminary paper (*Löhnis* and *Smith*, 1916 *a*, p. 679, footnote) we also said:

> We think it best to reserve the name "arthrospore" exclusively for those cases where the whole cell acquires the character of a spore.

However, a more thorough consideration of the problem has made the conclusion inevitable, that whole cells turning into resting forms should be named "microcysts," and the term "arthrospore" should be used for those spores which "like a chain of beads are formed by fission" according to *Jackson's* definition (given in his Glossary of Botanic Terms), which also agrees best with the etymology of the term, viz: τὸ ἄρθρον = the joint. It has been mentioned before that in this way the term "conidia," sometimes used for the aerial spores of Actinomyces, can be avoided, which is very desirable on account of its being frequently misused and also easily mistaken for "gonidia." If these reproductive organs of Actinomyces are accepted as type of arthrospores, their being produced by segmentation or fragmentation, their increased resistance, as well as their germination, can all be accepted as thoroughly studied by various investigators. Whether some process of fructification precedes the formation of these spores, must be left in

doubt at present, in the same manner as with regard to the endospores. That other bacteria are able to produce such arthrospores is beyond question. Those of the Proteus group are most generally known, but others formed by saprophytic spirochaets are also quite typical, as may be seen from the drawings made by *Gross* (1912, original figs. 8 and 9), which were reproduced as figure 63 on Plate O.

If the whole cell becomes more resistant by thickening its membrane, and sometimes also by reducing the amount of water present within the cell, the resting form produced may be termed "microcyst." The analogous cells of Nostoc have been called "heterocysts" by *Sachs* (1875, p. 215), those of Leuconostoc by *Van Tieghem* first "spores" (1879*c*), later "kystes" (1884, pp. 1105, 1108), and those of several spore-forming bacilli "chlamydospores" by *A. Meyer* (1901*b*), whose drawings, reproduced as figure 64 on Plate O (from original figs. 4 and 15 on Pl. XX), illustrate the difference of the microcysts when compared with *Gross's* picture of the arthrospores of spirochaets. The "spores" of Myxococcus exhibit also more the character of microcysts than that of arthrospores, though some similarities are noticeable in the latter direction, too, as may be seen from the drawing made by *Zukal* (1897), reproduced as figure 65 on Plate O (from original fig. 3).

Κυστις means cavity, bag, and a cyst is according to *Jackson* "a cell of nonsexual origin which reproduces the plant by germination after a resting period." The character of a bacterial microcyst fits this definition completely. That, however, the special name microcyst seems to be more recommendable in this case than the more general term cyst, is due to the fact, that the latter expression has been used in a different sense with the Myxobacteria, and that, as will have be shown in Chapter III, similar large cysts, i. e. "macrocysts," may also be formed by all bacteria when in the symplastic stage.

By some authors typical microcysts have been named endospores, a usage which can not be approved. *Migula* (1897, Vol. I, p. 169), for instance, insisted that *Van Tieghem's* Leuconostoc cysts had been endospores, because they had been brighter in the center and had germinated like endospores, though *Van Tieghem* clearly stated that the wall of the whole cell "se cutinise en déhors." *Prazmowski* expressed the analogous opinion in regard to resistent thickwalled cells of *Micrococcus ureae* (1888*a*) and of *Azotobacter chroococcum* (1912), despite the fact that the typical character of microcysts is especially noticeable in these cases.

The coiled and "encysted" spirochaets furnish another good example of the mode of formation of this type of reproductive organ, as well as of the correct use of the term.

That arthrospores and microcysts can not be easily distinguished when isolated is readily to be admitted. But the same holds true with regard to endo- and exospores, as well as in other cases, where the knowledge of the formation of the body in question is necessary in order to reach a scientifically correct classification.

(1) GONIDIA.

The formation of the gonidia is caused by a contraction and fragmentation of the content of the parent cell; though, naturally, the details of this process vary with the different groups of organism and to some extent with the cells themselves.

With the large trichobacteria, where *F. Cohn* (1870) first studied the formation of the gonidia, the cell content contracts itself into larger and smaller globules. When the cells break up within the sheath into 16 or more of such motile globular or ovoid granules, *Cohn* speaks of micro-gonidia; while he uses the term macro-gonidia, when only 2–4 are formed. But he himself emphasizes that both types of gonidia can not be sharply separated. The drawings made by *Billroth* (1874), which were reproduced as figure 45 on Plate L, demonstrate very clearly the characteristic formation and liberation of gonidia by some long bacilli, probably lactobacilli, as they were accumulated in whey kept at 40–45° C. The analogous description given by *Ewart* (1878) for the "sporules" of *B. anthracis*, as well as for the "bright, unusually small, almost spherical spores" of *B. termo* (fluorescens), and by *Geddes* and *Ewart* (1878) for the motile "spores" of spirilla, are also of considerable interest. A comparison of the last-named paper with those of *Perty* (1852), of *Fantham* (1911), and of *Bosanquet* (1911) leaves no

doubt that essentially the same process has been studied by all these authors (see figs. 42, 59, and 60, on Plates L and O). If the gonidia do not slip out at one end, as was sketched by *Fantham*, but are simply liberated by a complete dissolution of the cell wall, as has been observed with spirochaets, e. g., by *Bosanquet* and by *Rüther* (1910), the picture becomes very similar to what is a common occurrence with the Mycobacteria. *Lutz* (1886) made the first pictures of this process, as exhibited by *B. leprae*, reproduced as figure 36 on Plate J. Those published by *Kedrowski* (1910), reproduced as figure 37 on Plate J and as figure 153 on Plate XI, illustrate some other equally interesting phases in the formation of gonidia by this organism; they may be compared with those of the diphtheroid organism, drawn by *Babes* (1895) and reproduced as figure 34 on Plate J. The description given by *Bostroem* (1890) concerning the analogous behavior of Actinomyces also deserves our attention. The threads were seen to contain spherical, bright, "bead-like" granules, having the same diameter as the threads and being separated from each other by regular distances; they either slipped out of the sheath or became free by the dissolution of the cell wall. More recently *Hollandt* (1906) noticed that occasionally Actinomyces is able to produce micro- and macrogonidia in the manner characteristic for Crenothrix. That the same fact can be sometimes observed with smaller bacteria, too, has been demonstrated by *Miller* (1889), when he made his drawing of the so-called *Jodococcus vaginatus*, which was reproduced as figure 52 on Plate N. *Almquist* (1893) recorded analogous findings when he studied *B. coli* and *typhi; Prazmowski* (1912) and we (*Löhnis* and *Hanzawa*, 1914; *L.* and *Smith*, 1916) saw the same facts with Azotobacter.

The sketches made by *Morck* (1891) of nodule bacteria forming gonidia, which are reproduced as figure 66 on Plate P (from original figs. III, 4, and V, 12) show an interesting ring formation, which may be found with other bacteria, too; *P. Ernst* (1902), for instance, described this fact with *B. fluorescens*. That the gonidia may arrange themselves into such a circular grouping within the parent cell, while this retains its rod-form practically unchanged, has been recorded by *Trambusti* and *Galeotti* (1892) in the case of a bacillus from water.

Usually, however, the gonidia formed by such small rods as *B. coli, fluorescens*, etc., or by the larger ones of the Subtilis-Mesentericus group, appear simply as 2, 4, or more granules, arranged in one row. A photograph of *B. coli*, made by *Kellerman* and *Scales* (1916) from a contact preparate, has been reproduced as figure 182 on Plate XV; it allows one to recognize very clearly how abundant the gonidia may already be in young colonies. According to our own observations their number usually reaches the maximum, when the development of a culture is at its height. Figure 183 on Plate XV, reproduced from our first preliminary report (*Löhnis* and *Smith*, 1916 *a*, original fig. 39), pictures this phase in the life of a spore-forming bacillus (yellow bacillus No. 41) and makes a good object for comparison with the preceding photograph of B. *coli*.

With micro- and streptococci the gonidia formation becomes most conspicuous, when these very small bodies bud out of the parent cells, but remain temporarily attached to them by a very fine, rather long stem, a peculiarity which probably has been first seen by *Thiercelin* and *Jouhaud* (1903 *a*), and which is illustrated by our photographs of *Micr. candicans, luteus*, and *Strept. lactis*, reproduced as figures 168–170 on Plate XII. But again the analogous behavior can be traced through all groups of bacteria, as was ascertained by *Meirowsky* (1914 *b*), whose most characteristic drawings have been reproduced on Plate XIV.

Data relating to the formation of a single gonidium are not available at present. Some observations reported by *Fuhrmann* (1908), *Amato* (1908) and *Růžička* (1908) indicate, however, that this process is very similar to the initial steps in the formation of an endospore.

The production of gonidangia by the bacteria is quite general. Usually they are the result of a simple swelling of the parent cell; sometimes, however, the gonidia bearing rod first forms a circle, which later develops into a large coccoid body, as has been recorded for *V. proteus* by *Firtsch* (1888), for *B. radicicola* by *Morck* (1891), and for *B. fluorescens* by *P. Ernst* (1902). This process resembles very much another one noticeable with spirochaets, where the coiled forms first produce microcysts, which then act as receptacles for the gonidia, liberated inside

by the dissolution of the coiled spirochaets. *Perrin* (1906), *Dutton* and *Todd* (1907), and others have studied this transformation. The gonidangia of spirochaets, described by *Ross* (1912) and by *Moolgavkar* (1912), seem to have been, partially at least, of the same origin. They were either "large spherical cells, studded with small chromatin granules" or more irregular, pear-shaped bodies. In figure 67 on Plate P gonidangia of *B. radicicola* are reproduced from drawings made by *Morck* (1891, original figs. 2 *b–d* on Pl. III), to demonstrate an occurrence which has been also studied by *Hartleb* (1900), *Hiltner* and *Störmer* (1903), *Rossi* (1907), *Arzberger* (1910), and others.

That numerous observations upon the formation of bacterial gonidangia were made by some of the pioneers in bacteriology at the time, when the unscientific discarding of all "involution forms" was not yet an established rule, was mentioned in the historical résumé given on pages 90–108, especially on page 100, together with a very characteristic remark made by *Migula*. The early drawings of *Billroth* (1874), reproduced as figures 44 and 45 on Plate L, are excellent illustrations of the manner in which gonidia bearing rods may develop to voluminous gonidangia. The description given by *Toussaint* of the gonidangia of *B. anthracis* is equally worth quoting. In the textbook of *Magnin* and *Sternberg* (1884, p. 150) this otherwise unpublished observation was described as follows:

> In cultivating spores of the bacteria of charbon . . . *Toussaint* has seen the filaments take a transverse diameter almost double the ordinary diameter, then the protoplasm of the filament to gather together at certain points . . . Finally the points occupied by the condensed protoplasm augment considerably in volume and form some ovoid organs, more or less elongated, or swollen into a ball, or in the form of a gourd at one extremity. In the interior of these sporangia from three to six spores afterward form, . . . finally by breaking up of the membraneous envelope the spores become free.

Still earlier findings, recorded by *Letzerich* (1876–1878) in his experimental investigations upon diphtheria and typhoid fever, are not less interesting. He saw isolated cocci in the blood grow up into large plasmatic globules, which reproduced internally new bacteria. Some sketches, published in the first paper (1876, original figs. 1–4, on Pl. XII) are reproduced as figure 68 on Plate P, because they will possibly regain new importance in further investigations upon the "coccoid" form of diphtheria, mentioned on page 79, as well as in studies upon the relations existing between Bacteriaceae and Myxobacteriaceae. At the same time *Geddes* and *Ewart* (1878) gave the analogous description of the gonidangia formed by spirilla, while *J. Israël* (1878) noticed that the club-shaped cells of Actinomyces may serve the same purpose. The pear-shaped cells were seen to break up and to liberate their granular content. Exactly the same fact has been recorded by *E. Chr. Hansen* (1879–1894) with regard to the acetic acid bacteria, whose globular forms grew up to 11μ diameter. *V. cholerae* and related organisms have also frequently exhibited their large globular or club-shaped gonidangia, which have been fairly well studied by *Finkler* and *Prior* (1884–1885), *Ferrán* (1885) *Schroen* (1886–1890), and by *Dowdeswell* (1889–1890), though they remained to *R. Koch* and his followers always uninteresting "involution forms." A reference made by *Künstler* (1885) in regard to the gonidangia of spore-forming bacilli has been cited on p. 96. It is again in complete agreement with those mentioned before. In fact, *Künstler* (1885), as well as *Schroen* (1886), have already reached the conclusion that the production of gonidangia is a common occurrence within all groups of the bacteria. More data upon this subject have been furnished by the last-named author in two other papers (*Schroen*, 1890: Zur Genese der Microorganismen, and *Schroen*, 1904: Der neue Mikrobe der Lungenphthise). Unfortunately the author seems to have been unable to finish a special publication upon "The Genesis of the Microbes," which he promised in the second paper. Concerning the tubercle bacillus he wrote in 1890 that as with the cholera vibrio so also in this case globular forms may increase in size and become "mother spores," whose content divides itself into numerous coccoid "daughter spores." And with *B. anthracis* and *Megaterium* he noticed that the normal cells swell up into large somewhat irregularly curved "Bacillen-Säckchen," containing coccoid reproductive organs, which either are liberated as such, or transform themselves already internally into new small bacilli. The dividing up of the content of such gonidangia into only two large curved bacilli has been also

recorded by *Schroen* (1890), a possibility which was mentioned by *E. Klein* (1885) and by *Dowdeswell* (1890) with regard to *V. cholerae*, and later by *Hartleb* (1900) in his studies upon *B. radicicola.*

In his last paper *Schroen* (1904) comes to the conclusion that besides the tubercle bacillus another fungus-like organism acts as causative agent of phthisis, of which he gives among others the picture reproduced as figure 192 on Plate XV (from original fig. VIII). Apparently genuine hyphae are visible in the picture. However, it is more probable that these thick threads are no hyphae at all, but slime threads very similar to those produced by *B. radicicola* and the Myxobacteria. In Chapter III this point will have to be considered more fully. The round "capsules" of *Schroen's* organism, too, seem to be clearly bacterial gonidangia. According to his own description they produce 20 to 40 thin bundles of very fine threads, which, after their liberation, appear just like tubercle bacilli. As figure 189 on Plate XV Azotobacter gonidangia have been reproduced, which were interpreted by *Beijerinck* (1901 *b*, original fig. 4) as involution forms; they make a highly interesting counterpart to the "capsules" of *Schroen's* "phthisiogenic microbe," as well as to the gonidangia of the Pneumococcus, discovered by *Artigalas* (1885) and reproduced as figure 122 on Plate X. That with the streptococci again pear-shaped gonidangia may replace these perfectly round ones, has been shown by *Maddox* (1885), who observed the liberation of the deeply staining granular content of large club-shaped cells, present within or at the end of chains of *Streptoc. lactis.* With regard to his Enterococcus, *Thiercelin* (1899) wrote:

> On voit le coccus devenir très volumineux et donner naissance à un grand nombre de petits diplocoques vivement colorés au Gram, contenus dans une sorte de gangue amorphe, vaguement colorée par l'eosine.

The upgrowth of new small bacteria within the gonidangia, described by *Schroen,* has been also recorded by *Babes* (1895), whose drawings were reproduced as figure 53 on Plate N, as well as by *Gamaleia* (1900), who called these small forms "Mikromiten." That *Schmorl's* photographs of his *Streptothrix cuniculi* (*B. necroseos*), which were reproduced as figures 89 and 90 on Plate VIII, illustrate the formation of gonidia and gonidangia very well, will become apparent in this connection. *Hibler's* pictures of *B. Chauvoei,* shown on Plate X as figures 115 and 116, as well as that of *B. mallei* made by *Carpano* and reproduced as figure 96 on Plate VIII, deserve also to be recommended for a renewed comparative study. *Semmer* (1895) reported that tubercle as well as glanders bacilli produce big inflations filled with bright granules, like those to be found within the rods, which are able to reproduce rods and threads after being liberated. *Stoklasa* (1898) saw *B. Ellenbachensis* form "Blasen" and "Kugeln" with numerous motile granules, and *Růžička* (1908) obtained analogous results with *B. anthracis;* here the large globules were seen to liberate their granular content, which was interspersed with very small rods. In view of all these facts it is not easy to understand how *Fuhrmann* (1906–1913) could reach the standpoint and adhere to it that the process observed by him, viz., the formation of large pear-shaped cells or clubs containing and liberating either small motile granules or young rods, i. e., the development of typical gonidangia, be restricted to that group of bacteria which he happened to study (some Pseudomonas species), while it is, in fact, quite general with all bacteria.

The many inflations observed by *Hollandt* (1906) within thick threads of Actinomyces revealed their true character by the regular manner in which their content divided itself into 4 and 16 parts (gonidia). The resemblance to what *F. Cohn* called a "sporangium" of Crenothrix, reproduced as figure 43 on Plate L, is obvious.

On the other hand, *Herzog* (1910–1913), *Lehmann* and *Neumann* (1912), and others have noticed that the so-called giant forms of micrococci, especially those of gono- and meningococci, produce small granules, which the first author found able to reproduce normal cells. The similarity to the gonidangia of the streptococci, mentioned above, is again very clear. And if all these important facts would not have been so utterly neglected by the textbooks *Hort* (1917 *b*) certainly would not have been inclined to remove the meningococcus to the Hemiascomycetes, because once more he observed the upgrowth of normal cells to "giant forms," producing small granules, which in their turn became again normal cocci. A photo-

graph published in our first preliminary report (*Löhnis* and *Smith*, 1916 *a*, original fig. 5), illustrating the liberation of the gonidia from gonidangia of Azotobacter has been reproduced as figure 191 on Plate XV. With *B. fusiformis Rosenow* and *Tunnicliff* (1912) saw small "cocci" escape from the swollen ends of the threads. *Almquist* (1916) obtained small globules, as well as straight and curved rods, from the gonidangia of *B. typhi*. That the characteristic "involution forms" of *B. pestis* are also gonidangia is clearly indicated by the drawings made by *Albrecht* and *Ghon* (1900), which were reproduced as figure 11 on Plate D. The same holds true concerning the inflated big threads of *B. coli*, photographed by *Matzuschita* (1900) and reproduced as figure 36 on Plate III; and it is not to be doubted that many other so-called involution forms, especially most of the globular, pear-shaped, clubbed or otherwise inflated cells, so common within all groups of the bacteria, will find a similar explanation, as soon as adequate attention will be granted to them.

The form of the gonidia is usually, but not always, exactly spherical. Sometimes they are more or less ovoid, or even rectangular or square, as a result of the limited space wherein they are often compelled to grow. Their staining reaction changes necessarily according to their varying chemical composition. (See pp. 112–113.) Sometimes they refuse entirely to be stained by aqueous dyes, as was recorded, for instance, by *Esmarch* (1887) with *Spirillum rubrum*, by *Kedzior* (1896) with *Actinomyces thermophilus*, by *Kuntze* (1904) with *B. oxalaticus*, by *Růžička* (1908) with *B. anthracis*, by *Mencl* (1911) with Azotobacter, and by *Balfour* (1911 *a*) with spirochaets. But more often they stain as well as or even better than the parent cells. Thus were the results obtained, for instance, by *Finkler* and *Prior* (1884–1885) with *V. proteus* and *cholerae*, by *Bostroem* (1890) with *Actinomyces hominis*, by *Stoklasa* (1898) with *B. Ellenbachensis*, by *Thiercelin* and *Jouhaud* (1903) with Enterococcus, by *Tunnicliff* (1906) with *B. fusiformis*, and by *D. H. Jones* (1913) with Azotobacter. When treated with Gram's method, the gonidia are often stained, even if the cells themselves are Gram-negative. *B. radicicola* and its relatives are prominent examples in this direction (*Löhnis*, 1905 *a*). Occasionally special staining methods may give good results, as were secured e. g. by *A. Neisser* (1888) with *B. xerosis*, and by *Bliesener* (1901) with *V. cholerae*, while the gonidia of *Esmarch's Spirillum rubrum*, on the other hand, could not be stained by any of these methods. The metachromatic reaction of the gonidia to methylen blue seems to be fairly constant, according to *Babes* (1895, 1907 *a*, 1914) and *Fuhrmann* (1906–1908). The Romanowsky method gave *Balfour* (1911 *a*) only negative results with the "infective granules" of spirochaets. *Herzog* (1910), on the other hand, noticed that the gonidia of gono- and meningococci turned red when treated with Giemsa's modification of the Romanowsky stain; but when growing up to the full size of the parent cell they assumed more and more the normal deep violet color.

Active motility seems to be more frequent among the gonidia than among their parent cells. *Geddes* and *Ewart* (1878), *Künstler* (1885), and *Dowdeswell* recorded this fact with gonidia produced by spirilla. *Heydenreich*, *Guttmann* (1880), and *Albrecht* (1881) were the first to report the same occurrence with spirochaets. *Beijerinck* (1888), *Frank* (1890), *Atkinson* (1893), *Greig-Smith* (1900), and many others have studied the "swarming bodies" or "zoospores" of *B. radicicola*. Motile gonidia of Actinomycetes were observed by *Eppinger* (1890), *Rullmann* (1896) and *Kedzior* (1896), of *B. anthracis* by *Podwyssotzky* and *Taranoukhine* (1898), of *B. oxalaticus* by *Kuntze* (1904), of *B. subtilis* by *Marrassini* (1913), and of Azotobacter by *D. H. Jones* (1913). Photographs made by the two last-named authors were reproduced as figures 160 and 161 on Plate XII. It is hardly necessary to emphasize, that the minute size of the gonidia makes it especially imperative to distinguish sharply between active motility and Brownian movement. Comparative tests without and with antiseptics are often advisable.

The development of the gonidia may start either inside or outside of the parent cell. If the gonidia are not liberated by the partial or complete dissolution of the cell wall, but remain confined within the cell, they develop into either buds or branches. The great multitude of forms which results from such development, may be seen from the pictures of *B. coli* and *typhi*, made by *Hort* (1917 *a*) and reproduced as figures 179 and 180 on Plate XIII. *Zopf* (1879) was apparently the first to notice this formation of branches in the case of Crenothrix. *Migula*

(1900) has later assumed that the gonidia do not germinate inside, but outside, of the cell wall, to which they were said to be sticking; and he illustrated his theory by the drawings reproduced as figure 69 on Plate P (from original fig. 43 *f* and *g*). However, observations made by *Rullmann* (1907) and by *Ellis* (1907–1910) have confirmed *Zopf's* findings, not *Migula's* assumption. *Hollandt* (1906) got analogous results with the large Crenothrix-like threads of Actinomyces, which he discovered. *Spirillum endoparagogicum*, as described by *Sorokin* (1887), is the only example of this kind of bacterial development which has been frequently quoted in the textbooks. A glance at his drawings, reproduced as figure 29 on Plate H, will suffice to show that, in fact, it was by no means such an exceptional occurrence as it has been usually considered to be. *Kutscher* (1895) recorded similar findings with *Spirillum Undula*, and *Meirowsky* (1914 *b*) has proved the general occurrence of such branching. His drawings, reproduced as figure 30 on Plate H and on Plate XIV, make interesting counterparts to *Sorokin's* sketches. The lateral germination of the gonidia in *B. xerosis*, as studied by *A. Neisser* (1888), has been another early and exceptionally clear observation of the same principle. *Eppinger* (1890), too, followed carefully the gradual development of the gonidia, appearing within the threads of his *Cladothrix* (i. e. *Actinomyces*) *asteroides*, first into buds, and later into branches. In regard to the typhoid bacillus *Almquist* (1893) was the first to point out that its multiplication is not only caused by fission, but also by producing new rods by budding and branching. His later publications (*Almquist*, 1904–1918) confirmed and extended these findings, now also with respect to *V. cholerae*, *B. dysenteriae* and *paratyphosus*. The sprouting of very thin, needle-like rods, to which the Swedish author paid special attention, is also well noticeable in *Hort's* drawings of *B. typhosus* on Plate XIII (fig. 179).

The results recorded by *Escherich* (1894, p. 87) with *B. diphtheriae* are practically duplicating those of *A. Neisser* with *B. xerosis*, and the description given by *Fraenkel* (1895) of the formation of branches by the diphtheria bacillus is in complete agreement with that given by *Eppinger* for *Actinomyces asteroides*. *Hill* (1902) has pointed out that not always a granule is visible at the base of a branch in *B. diphtheriae* and that its presence, therefore, is not closely connected with the formation of the branch. This point needs further study. It may be that the bacteria are also able to produce branches in the same manner as the fungi do, but this fact, of course, would not interfere with the special rôle played by the growing gonidia in the life of the bacterial cell.

A close relation between the "metachromatic granules" and the formation of buds and branches by various bacteria has been emphasized by *Babes* (1895). *Kedzior* (1896), too, noticed how bright granules contained within the threads of his thermophilic actinomyces extruded into buds and branches. The observations made by *Stolz* (1897) with a diphtheroid organism, by *Craig* (1898), *Cornet* and *Meyer* (1903, p. 83) and by *Fontes* (1910) with *B. tuberculosis*, by *Conradi* (1900) with the glanders bacillus, by *Neukirch* (1902) and by *E. Levy* (1902) with Actinomycetes, by *Greig-Smith* (1900), *Faber* (1912) and *Georgevitch* with *B. radicicola* and *Mycobact. Rubiacearum*, and by *Bajardi* (1903) with *V. lingualis*, all confirm this relation. Most of these authors report that the chromatin granule, which *Georgevitch* called "le centre cinétique," slips into the young branch, where it is to be found at its apex.

A photograph made by *E. de Negri* (1916, original fig. 27), showing excellent budding of her Corynebacterium causing malignous granulom, has been reproduced as figure 184 on Plate XV. Another one of *B. coli*, made by *Kellerman* and *Scales* (1916) is to be seen in figure 185 on Plate XV. The next two pictures (figs. 186 and 187) are reproductions from our first paper (*Löhnis* and *Smith*, 1916 *a*, original figs. 3 and 4); both present budding Azotobacter cells, the last one furnishing an especially clear insight into the relation existing between branches and gonidia retained within the parent cell.

The development of the gonidia within or while still united with the parent cell may also lead to some other modes of development. Figure 188, reproduced from our second preliminary report (1916 *b*, original fig. 1) illustrates a case where the budding gonidia grew up to full sized cells, which now give the parent cell a queer, turtle-like appearance. More frequent, however, although rare compared with the common budding and branching, is the development of full-sized cells from the gonidia while still confined within the parent cell. Naturally, only large

cells like Azotobacter offer sufficient space for such direct internal upgrowth. Figures 190 and 193 on Plate XV, reproduced from our first paper (1916 *a*, original figs. 6 and 21) may illustrate this possibility. *Prażmowski's* (1912) report on Azotobacter contains some similar drawings. The giant Bacterioidomonas, discovered by *Künstler* (1884), which was later described anew as Metabacterium by *Chatton* and *Pérard* (1913), whose drawings were reproduced as figure 50 on Plate M, furnishes an interesting counterpart. With the smaller bacteria such kind of upgrowth is only possible, of course, after the parent cells have enlarged themselves to gonidangia, becoming the "Bakteriensäckchen" of *Schroen* (1890) or the "Ammen" of *Finkler* and *Prior* (1884). The sketches made by *Tomaschek* (1888) and by *Babes* (1895), which were reproduced as figures 51 and 53, Plate N, should be compared in this respect. The large cells of the protean air bacillus studied by *Matzuschita* (1902) furnish another example in this direction. (See fig. 5 on Plate B.)

If the gonidia are liberated as such, their further development, quite naturally, is subject to many more uncertainties. They may become free by a complete dissolution of the cell wall or they may emerge at one point as a "cloud" or as a string of granules embedded in a small or large quantity of other plasmatic material. What *Meirowsky* (1914 *b*) called "umbels" (Dolden) have been evidently in some cases such masses of liberated gonidia, while in other cases it seems more probable that flakes of symplasm have been present, as may be seen from his drawings reproduced on Plate XIII (fig. 178) and on Plate XIV.

A sufficient supply of nutrient material furnished by the parent cell undoubtedly assures and facilitates the new development considerably. The starlike arrangement occasionally noticeable with all bacteria may be caused by the outgrowth of young rods from such liberated cell content, as was illustrated already by one of our Azotobacter photographs, reproduced as figure 176 on Plate XII. *Hort's* pictures on Plate XIII (figs. 179 and 180) contain some similar stars, produced by *B. typhosus* and *B. coli*. They have been frequently observed with *B. radicicola* and *radiobacter* by *Beijerinck* (1888), *Beijerinck* and *Delden* (1902), and myself (*Löhnis*, 1905 *a*). Not all stars, however, are the result of this kind of development. In Chapter III a radiate outgrowth from the symplasm will have to be mentioned, and in Chapter IV a similar grouping of full-grown bacteria in the conjunct stage.

If the amount of nutrient material supplied by the parent cell is insufficient, or if it is quickly dispersed by dissolution, the development of the liberated gonidia depends preeminently on the substrate which they will find. *Lagerheim* (1900) observed that the gonidia of his *Sarcinastrum Urosporae* increased in size and germinated to new rods only if they had a chance to settle down on their natural substrate, viz., a thread of Urospora. When discussing the behavior of the filterable gonidia more examples will have to be mentioned which furnish some valuable information concerning the important effect which the substrate exerts in such cases. In artificial cultures often no upgrowth was noticeable on account of unsuitable environmental conditions; not a few failures, however, have been caused, as may be safely assumed, by the widespread inclination to consider "granular decomposition" and "autolysis" of the bacteria as full proof of their death and therefore justifying the discarding of all such cultures. That this custom does not take into account the important rôle played by the symplasm in the life history of the bacteria will be proved by the facts to be discussed in Chapter III. At present it may suffice to refer only to the observations made by *Fuhrmann* (1906) with regard to the behavior of the metachromatic granules (i. e. gonidia), imbedded in the "detritus," which results from the disintegration of the club-shaped gonidangia of *Pseudomonas cerevisiae* and related forms. He reports that at the end of the life cycle there were present only—

die stärker lichtbrechenden, mit Methylenazur rot-violett färbbaren Kügelchen, aus denen sich wieder bewegliche Kurzstäbchen rückbilden, sobald der Detritus auf einen neuen Nährboden übertragen wird.

If the conditions are not favorable to an immediate upgrowth of normal cells, the gonidia may multiply as such for a considerable length of time, either by fission or by budding. This mode of development was reported in 1865 by *Hallier* for the so-called *Leptothrix buccalis*. In 1878 *Geddes* and *Ewart* studied the same process with some water spirilla, and at the same

time *J. Israël* with Actinomyces. *Zopf* (1879–95) saw the gonidia of Crenothrix and of Beggiatoa behave in the same manner. Analogous results were recorded with *B. anthracis* by *Archangelski* (1883), with *B. Chauvoei* by *Ehlers* (1884), with *B. allantoides* by *L. Klein* (1889), with *B. coli* by *Almquist* (1893), by *Adami, Abbott* and *Nicholson* (1899) and by *M. E. Abbott* (1900), with *B. typhosus, paratyphosus, dysenteriae,* and *pseudodysenteriae* by *Almquist* (1893–1908), with *V. cholerae* by *Cunningham* (1897), by *Almquist* (1904–8), and by *Stamm* (1914), with various spirochaets by *Wechselmann* and *Löwenthal* (1905), *Henry* (1913) and others, with *B. tuberculosis* by *Fontes* (1910), and by *Maher* (1910–1915), with Azotobacter by *Prażmowski* (1912). Macroscopically this kind of development is usually very inconspicuous; on solid substrates nothing more will be seen than a very thin dewy layer without any pigmentation, while in liquids either a weak turbidity or a fine cloud of sediment becomes noticeable. Nevertheless, the pathogenicity may be fully retained as was discovered by *Archangelski* in 1883.

In those cases where the environmental conditions allow an upgrowth of the liberated gonidia, they may, as it is also very often done by the gonidia budding out from the parent cell, first develop to regenerative bodies before reproducing normal vegetative cells. This possibility will be discussed later. The direct germination of a new vegetative cell from a gonidium has been first recorded by *Perty* (1852). *Hallier* (1865) and *Karsten* (1869) probably observed the same process, which then was firmly established by *F. Cohn* (1870) by his investigations upon the germination of the gonidia of Crenothrix. *Rindfleisch* (1872) made some interesting drawings of germinating gonidia, which were reproduced as figure 41 on Plate K. *Zopf* (1879) confirmed *Cohn's* findings, but he also pointed out that by no means all gonidia can be expected to germinate promptly when placed under the microscope. In his important investigations upon the gonidangia formation of *B. anthracis, Toussaint* (1884) also studied the upgrowth of new rods from the liberated gonidia. The same has been done with *V. cholerae* by *Dowdeswell* (1889), *Bliesener* (1901), *Fedorowitsch* (1902) and *Almquist* (1904), with *V. proteus* by *Finkler* and *Prior* (1884–1885), and by *Firtsch* (1888), with other spirilla by *Künstler* (1885), with *Actinomyces hominis* by *Bostroem* (1890), with *B. coli* and *typhosus* by *Almquist* (1893)and by *Fedorowitsch* (1902), the latter in addition recorded analogous results with *B. pyocyaneus, cholerae gallinarum, septicaemiae murium, diphtheriae,* and *tuberculosis,* with *B. diptheriae* also by *Cache* (1901), with *B. tuberculosis* by *Arloing* (1908), with *B. mallei* by *Marx* (1899), with Enterococcus by *Thiercelin* and *Jouhaud* (1903), with *B. fusiformis* by *Tunnicliff* (1906) with *Spirochaeta gallinarum* by *Hindle* (1911), and with Azotobacter by *Prażmowski* (1912). Practically this germination consists merely in an expansion and stretching of the small gonidium to the normal size of the vegetative cell, as it was pictured, for instance, by *N. K. Schultz* (1901 *a*) with *B. pestis.* (See fig. 58 on Pl. O.) Sometimes the original membrane may be left behind, which fact naturally is more easily discovered with the large trichobacteria than with smaller species. Drawings made by *Billet* (1890) of germinating *Cladothrix* gonidia, reproduced as figure 70 on Plate P (from original figs. 4 and 5 on Pl. IV) may serve as an illustration. *Woloschin* (1913) once observed that under certain conditions the capsules of *B. anthracis* break up, and that then from these apparently empty broken sheaths new bacilli may germinate, a fact which induced him to formulate the somewhat vague hypothesis, that the substance of the capsules itself be endowed with an "embryonic life". Undoubtedly, it is much more probable that those unstainable gonidia, especially frequent with spore-forming bacilli, after budding out from the parent cell have remained within the equally unstainable capsule, thus apparently becoming a part of it.

That the resistance of the gonidia is not much higher than that of the vegetative cell has been pointed out before. They are organs for multiplication and reproduction and do not possess any special protection against deleterious influences, except that given by the higher concentration of their plasmatic body and by the resulting reduction in moisture content. Naturally they can not withstand boiling water, but it has been frequently noticed that other noxious influences active in nature which destroy the life of the vegetative cell can be endured by the gonidia, which, therefore, also in this respect may occasionally play an important rôle. *Finkler* and *Prior* (1885), for instance, ascertained that the gonidia of their vibrio proved to be

only a little more resistant at 65° C., but much more so against sharp drying at room temperature (above P_2O_5); and in old cultures they retained their reproductive power for months. According to *Esmarch* (1887) dried cultures of his *Spirillum rubrum*, which had not yet produced their gonidia, died within 6–8 days, while the vitality under the same conditions was fully retained for more than five weeks, when the gonidia were formed, though these also in this case were killed in water of 52° C. within five minutes. *Bliesener* (1901), too, found that the gonidia of *V. cholerae* were killed if exposed to 50° C. for 30 minutes. Sharp drying also proved to be detrimental; but in water the vitality was retained for nearly three years, and the author, therefore, thinks that under natural conditions they may occasionally conserve the life for a considerable length of time. The results obtained by *N. K. Schultz* (1901) with *B. pestis*, and by *Rothert* (1902), as well as by *Fedorowitsch* (1902) and by *Martini* (1910) with several other non-spore-forming bacilli (*Staphyloc. pyogenes*, *Streptoc. pyogenes*, *B. coli*, *typhosus*, *dysenteriae pneumoniae*, *pyocyaneus*, *septicaemiae*, and others) were quite similar. Old sealed cultures of the plague bacillus were found by *Schultz* to be still alive after four years, and *Fedorowitsch* reported that a culture of *B. pyocyaneus* died within 3–8 days, if it was dried when only 5–6 hours old, but that it lived for 38 days when it was allowed to grow 24 hours, so as to form gonidia before being dried. With *Bac. cholerae gallinarum* the following data were recorded:

Age of culture before drying	4–8 hours.	24 hours.	5 days.
Limit of vitality was reached after	22–25 days.	97 days.	84 days.

B. coli was completely killed, according to *Schultz* and *Ritz* (1910), if a 3–6 hours culture was kept for 25 minutes at 53° C., while 12–24 hour cultures gave about the same number of colonies on the plates made from the not heated and from the heated suspensions.

The very considerable resistance of diphtheria and tubercle bacilli against drying, which *Chester* (1901) connects with the presence of "gonidia", is evidently due to their having changed into the more resistant regenerative bodies, though a somewhat greater resistance of the genuine gonidia in this case is also quite probable. *Jessen* and *Rabinowitsch* (1910)reported that the small acid-fast granules of tubercle bacilli remain intact, when the bacilli themselves are solved by caustic alkali. The so-called granular decomposition of cholera and of other organisms in the serum is undoubtedly, partially at least, another indication of the increased resistance of the gonidia. And the same holds true with regard to the fact that slightly detrimental influences, which reduce the vitality of the vegetative cells, stimulate the formation of the gonidia, a fact which has been studied by *Ruata* (1905) with *V. cholerae*, which was treated with free ammonia. *Balfour* (1911 *a*) has emphasized the greater resistance of the gonidia of spirochaets against salvarsan, and the resulting difficulty in curing chronic spirochaetosis. This point deserves to be studied, mutatis mutandis, in other chronic diseases, too.

(2) REGENERATIVE BODIES AND EXOSPORES.

According to the definition given on page 121 the so-called regenerative bodies are produced either by the gonidia or by the symplasm. It would be preferable if only the first category of them could be considered here and the others be left to Chapter III. But the data available at present often do not allow such a sharp distinction, and therefore the subject must be treated in a somewhat loose manner. Details relating to the transformation of the symplasm into regenerative bodies will be discussed in Chapter III; the appearance and behavior of the fully developed regenerative bodies, however, will be better considered here, as it is often not only difficult, but even impossible to decide exactly whether observations recorded in the literature refer to regenerative bodies developed from the gonidial or from the symplastic stage.

The first type of formation of regenerative bodies, consisting in the upgrowth of gonidia to bodies of larger size and of more solid structure, is very common among the bacteria and has been noticed, therefore, by many investigators. Especially the development of the large deeply staining globular regenerative bodies at the side or at the end of the normal bacteria, has often evoked more or less interest. The photographs reproduced as figures 116, 124, 126–129 on Plate X, nearly all on Plate XI, figures 170–172 on Plate XII, those on Plate XIII, and the drawings made by *Henneberg* (1898), which were reproduced as figure 57 on Plate X,

will convey some idea of their general occurrence. In addition, a few drawings made by *Niessen* (1898) from his so-called syphilis bacillus have been reproduced as figure 194 on Plate XV, because they demonstrate especially well the characteristic appearance of this type of reproductive organs. The following description, given by *Fuhrmann* (1906) also deserves to be quoted; after having discussed the rôle played by the "clubs" (i. e. gonidangia) in the life history of *Pseudomonas cerevisiae* and related species he continues:

> Es sind noch eigentümliche Bildungen zu nennen, die dann auftreten, wenn die verlängerten Stäbchen in optimale Lebensbedingungen gebracht werden. Es bilden sich dann am Stäbchen kleine Wärzchen, die sich vergrössern und endlich ablösen und frei in der Flüssigkeit schweben. Bei manchen von ihnen kann man nun eine Aufteilung des Inhaltes beobachten. Die Teilstücke werden dann frei und gleichen allerkleinsten Stäbchen und Pünktchen.

When the formation of the regenerative body takes place at the end of the cell, the resulting picture resembles very much that of a plectridium, but the regular bright spore is replaced by the deeply staining regenerative body. The drawings reproduced as figure 71 on Plate P may illustrate this possibility. They were taken from a paper upon *Spirochaeta icterohaemorrhagica*, published by *Inada, Ido, Hoki, Kaneko and Ito* (1916, original figs. 40–47 on Pl. 61).

With micro- and streptococci it is often difficult to discern exactly whether the body formed should be classed as regenerative body or as microcyst. Our photographs of *Microc. candicans*, reproduced as figure 168 on Plate XII, and the drawings made by *Babes* (1895) of branching streptococci, reproduced as figure 3 on Plate B, may serve as examples in this direction. On the other hand, our photograph of *Streptoc lactis*, reproduced as figure 170 on Plate XII, demonstrates equally well the budding out of the gonidium and its upgrowth to a lateral regenerative body. A picture of *Streptoc. pyogenes* published by *Hewlett* (1902) and reproduced as figure 72 on Plate P (from original fig. II*a*) shows the same details, as does also the first sketch of those made by *Hlava* (1902) of his *Leuconostoc hominis*, which have been reproduced as figure 4 on Plate B.

Among the nonspore-forming short rods very instructive preparates are easily obtainable especially with *B. radicicola* and with the lactobacilli (*B. acidophilus, casei*, etc.). Two characteristic photographs of *B. radicicola* made by *Hiltner* and *Störmer* (1903, original figs. II, 1 and 2) are reproduced as figures 195 and 196 on Plate XV. *Bac. bulgaricus* has been shown in figures 148 on Plate XI and 172 on Plate XII; other pictures of closely related organisms may be found in papers of *Weigmann, Gruber* and *Huss* (1907), *Kuntze* (1908), and *White* and *Avery* (1909). The picture made by *Tissier* (1900) of *B. bifidus*, reproduced as figure 8 on Plate C, is also of interest in this connection. Some of the photographs by *Almquist* (1916–1917), showing regenerative bodies of *B. typhosus, dysenteriae* and of other nonspore-forming bacteria, were reproduced as figures 135–138 on Plate XI.

The branched threads of *B. subtilis* reproduced as figure 197 on Plate XV from our second preliminary paper (*Löhnis* and *Smith*, 1916 *b*, fig. 27) exhibit at the same time small, pale, budding gonidia, well developed regenerative bodies in lateral, as well as in terminal, position, and also an unstainable body, apparently a growing exospore. Interesting details concerning the formation of regenerative bodies by the gonidia of Azotobacter have been published by *Prazmowski* (1912, pp. 145–147), who paid special attention to their development from the liberated gonidia. The so-called micro-oidia, described by *Bredemann* (1909) for *B. Amylobacter* and by *Viehoever* (1913) for *B. Pasteurii*, are probably also to be classed as regenerative bodies, though they have not been seen to reproduce normal rods. Similar round forms have been observed by *E. Klein* (1883) with *B. anthracis*, but here their formation, as well as their ability to reproduce normal rods, have been carefully studied and ascertained.

With spirilla and vibrios lateral, as well as terminal, regenerative bodies are equally frequent. The so-called arthospores of *V. cholerae* found by *Hueppe* (1885), whose drawings have been reproduced as figure 49 on Plate M, as well as those described by *Firtsch* (1888) for *V. proteus*, have been either regenerative bodies or exospores. The deeply staining resistant organs described by *Weibel* (1888) for his *V. lingualis* are also to be classed as regenerative bodies.

With spirochaets these lateral or terminal swellings are still more conspicuous, and they have been noticed accordingly by practically all authors, who have made such studies. *Künstler* (1885) probably has been the first to mention this occurrence, when he described his "Proteromonas Regnardi." The spirilliform organism isolated by *Calmette* (1893) from typhus cases, whose "spores" were found either to multiply as such (by budding) or to reproduce new "spirilla," apparently also belongs in this group. More recent and more complete, though often misinterpreted, evidence relating to spirochaets has been furnished by *Prowazek* (1906), *Mühlens* and *Hartmann* (1906), *Schaudinn* (1907), *Fantham* (1911), *Hindle* (1911), *Noguchi* (1911–1912), *Wolbach* (1914), *Meirowsky* (1914), *Inada, Ido, Hoki, Kaneko* and *Ito* (1916), as well as by *Leishman* (1918). *Noguchi* (1912) has pointed out with good reason, that these formations "should not be viewed as the result of plasmoptysis" because "the number of the organisms with round bodies . . . seems to become greater where the growth of the culture approaches its maximum" and the development of new spirochaets from these bodies also has been observed. Some very interesting pictures made by *Inada* et al. (1916) have been reproduced as figure 31 on Plate H; they make a good counterpart to our Subtilis photograph (fig. 197 on Plate XV).

That fusiform bacilli behave in the same manner as spirochaets do, was noticed by *Ellermann* (1907), but he discarded the round bodies once more as "involution forms."

Most frequently their presence has been recorded with the Mycobacteriaceae. The fairly resistant, but easily stainable round reproductive organs formed usually at the ends, but also at the sides of *B. tuberculosis, leprae, mallei, diphtheriae*, and *pseudo-diphtheriae* have attracted considerable attention. The earliest observations in this direction have been those of *A. Neisser* (1881) and *G. A. Hansen* (1882) upon the formation of globular "spores" of *B. leprae*. They were confirmed by *Babes* (1883), who in addition discovered the analogous organs of *B. tuberculosis*, and more completely by *Lutz* (1886). Similar results were later recorded for *B. leprae* by *Bordoni-Uffreduzzi* (1888*a*), *Czaplewski* (1898) and by *Meirowsky* (1914*b*), for *B. mallei* by *Semmer* (1895), *Galli-Valerio* (1900) and by *Carpano* (1913), for diphtheroid organisms by *Nakanishi* (1900*c*) and by *E. de Negri* (1916), for *B. diphtheriae* by *Bergstrand* (1918), for *B. tuberculosis* by *Sander* (1893), *Semmer* (1895), *Crookshank* (1896), *Droba* (1901), *W. Ernst* (1902), *Meier* (1903), *Schroen* (1904), *Rosenblat* (1905), *Betegh* (1908), *Meirowsky* (1914*b*), and by others.

The deeply staining "spores" seen by *Schütze* (1908) to grow singly at the end of the branches of *Actinomyces monosporus* evidently have also been regenerative bodies, and the same seems to hold true with regard to the spherical spore-like body found by *Metchnikoff* (1888*b*) to be produced within the club-shaped cells of his *Pasteuria ramosa*.

The form of the terminal regenerative bodies is either globular, oval, or pear-shaped, while those in lateral position are either spherical or kidney-shaped. After being liberated, they all seem to assume a perfectly spherical form. Whether the regenerative bodies of irregular shape, frequently to be seen in the cultures, are exclusively produced by the symplasm or by normal vegetative cells, also, can not be decided at present. The first-named possibility, however, seems to be more probable.

All regenerative bodies take the stain very readily, so that under the microscope, as well as in the photographs, these comparatively large dark bodies are very conspicuous.

Motility seems to be absent as a rule. In those cases, where motile gonidia grow up to regenerative bodies after being liberated, these too, may retain motility for some time, though it is, of course, under such conditions a more or less disputable point, at what moment the "gonidium" actually becomes a "regenerative body." Especially with *V. cholerae* repeatedly large globular bodies have been observed, e. g. by *Dowdeswell* (1889), *Hammerl* (1906), *Almquist* (1908) and *Bittrolff* (1912), which, indeed, may have been motile regenerative bodies. *Almquist* (1907) reports, that also in the case of *B. typhi* he saw motile globules separate themselves from the bacilli, which being able to germinate promptly apparently have been genuine regenerative bodies.

Further development from the regenerative bodies is naturally more easily to be ascertained than it is usually the case with the gonidia. But here again occasionally fragmentation and dissolution may be seen, which processes should not be taken by themselves as proof of "involution" and death. Generally the irregularly shaped regenerative bodies seem not to be able to reproduce directly normal vegetative cells. One often sees them either breaking up into round regenerative bodies, which germinate later, or melting together to a flake of symplasm, which in its turn may produce either directly normal vegetative cells or another set of regenerative bodies of regular shape. Such fragmentation and dissolution have been repeatedly reported, for instance with so-called bacteroids of the root-nodule bacteria by *Beijerinck* (1888), *Moeller* (1890), *Hiltner* and *Störmer* (1903) and others. The irregular regenerative bodies of spore-forming bacilli, as well as those of micrococci, behave in the same manner, as was discussed in our preliminary papers (*Löhnis* and *Smith*, 1916 *a* and *b*). That *Buchanan* and others have seen the "bacteroids" of *B. radicicola* proliferate as such or produce small motile rods by segmentation, should not be considered to be irreconcilable with the facts just mentioned. "Bacteroids" behaving in this manner are merely branched vegetative cells, which may be morphologically more or less similar to those other forms, though they are different physiologically.

The globular regenerative bodies are much inclined to multiply as such, before reproducing normal vegetative cells. Like the gonidia, they multiply by budding as well as by fission; both processes may be often seen to proceed side by side in the same preparation. The resulting "pure cultures" of budding, relatively large, coccoid cells may look very similar, though actually belonging to entirely different organisms. *Eyre* and *Washburn* (1897) obtained such a luxuriantly growing, avirulent, gelatin liquefying culture of resistant micrococci from a typical pathogenic Pneumococcus. Numerous photographs, reproduced on our plates, illustrate the analogous behavior of various species as observed by different authors. These are:

II, 18: *Bact. bruneum* (*fluorescens* var.), *Matzuschita* (1900).
III, 30: *Bact. cholerae gallinarum*, *Itzerott* and *Niemann* (1895).
III, 35: *Bact. pestis*, *Rowland*, (1912).
V, 59: *Bac. anthracis. Henri* (1914).
VI, 68: *Bac. Azotobacter*, *Löhnis* and *Hanzawa* (1914).
VIII, 91: *Bac. mallei*, *Carpano* (1913).
IX, 97: *Bac. diphtheriae*, *J. Dale* (1910).
IX, 98: *Bac. variabilis lymphae vaccinalis*, *Nakanishi* (1900*c*).
IX, 101: *Corynebacterium of malignous granulom*, *E. de Negri* (1916).
IX, 104: *Bac. tuberculosis*, *Arrigo* (1900).
XI, 146: *Streptococcus lanceolatus*, *Axelrad* (1903).
XI, 147: *Bact. coli*, *Axelrad* (1903).
XII, 154: *Bac. leprae*, *Kedrowski* (1910).
XII, 155 and 156: *Meningitis bacillus*, *Ghon*, *Mucha* and *Müller* (1906).
XII, 157: *Bact. cyanogenes*, *Neelsen* (1880).
XII, 158: *Vibrio cholerae*, *Hammerl* (1906).

That the presence of these globular regenerative bodies in practically pure growth within the organism may sometimes cause serious diagnostic errors, has been already mentioned with regard to diphtheria on pages 79 and 80. The general occurrence of such deceptive forms within all groups of bacteria is certainly of considerable importance, and a careful study of their morphological and physiological behavior is much to be recommended. In this connection an observation made by *Calmette* (1893) in regard to a spirilliform organism, isolated from typhus cases, is of interest. The round regenerative bodies grew constantly as such, multiplying by budding, when they were kept on an acid substrate, while an alkaline reaction and substrates rich in albumines stimulated their germination and the regeneration of spiral forms.

It seems not unlikely that several descriptions of so-called cocci actually refer to regenerative bodies of other species. If these "cocci" later changed to rods, or if in old cultures of bacilli such "cocci" have appeared, the "contamination" theory undoubtedly has been often invoked erroneously. I myself have to plead guilty, that for nearly two years I have rejected as "impure" actually pure cultures of aerobic cellulose destroying bacteria, which had been isolated by *Grant Lochhead* (unpublished investigations 1912–1914), because careful examination

of his preparations invariably revealed the reappearance of "cocci," which, as our later studies (*Löhnis* and *Smith*, 1916*b*) have brought out, are constantly to be found in this as in every other group of bacilli. What perplexing pictures are to be had especially from these aerobic cellulose destroying rods may be seen from figure 265 on Plate XXI, which was reproduced from the last-named paper (orig. fig. 52). It was made from a frequently tested pure culture of *Bact. acidulum*, originally described by *Kellerman, McBeth, Scales* and *Smith* (1913) as a slender short rod (average dimensions $1.0 \times 0.3\mu$).

Even with regard to the Nitrosococcus of *Winogradsky* it is by no means improbable that this is no coccus at all, but a pure culture of regenerative bodies of Nitrosomonas. The photograph made by *Winogradsky* (1891), reproduced as figure 198 on Plate XV, shows besides round cells of rather different size, i. e., a peculiarity much more frequent with regenerative bodies than with genuine cocci, some small short rods, which according to *Winogradsky* represent an "impurity;" the photograph is said to have been made from a "vieille culture sur silice, déjà devenue un peu impure." However, in the lower right corner of figure 198 we see a larger rod connected with a round body exactly in the same manner, as it is shown by all bacilli when producing regenerative bodies and in the upper left corner something like a torn, empty membrane is visible, whose presence also fits much better to the theory that regenerative bodies, not genuine cocci, are represented in this picture. Additional evidence will be furnished in Chapter III. A comparison of figures 198 and 195 (Nitrosococcus and regenerative bodies of *B. radicicola*) is also to be recommended.

The multiplication of irregularly shaped rod-like regenerative bodies is sometimes to be observed with micrococci, and occasionally it becomes so firmly established, that the cultures present a picture much more resembling an Actinomyces than a Micrococcus. Figures 2–6 and 8 on Plate I illustrate this possibility. It is readily to be admitted, of course, that our present knowledge often leaves us in doubt, whether such forms should be classed as regenerative bodies or as truly vegetative cells. Their staining reaction, as well as their ability to reproduce regular micrococci, may often serve as a valuable indication, and their development from the symplasm may supply additional evidence. Further investigations, however, are indispensable to learn more upon the vegetative or reproductive character of such forms.

The germination of rod-like forms from round regenerative bodies has been observed quite frequently viz. with *B. cyanogenes* by *Neelsen* (1880), with *B. typhosus* by *Almquist* (1904), with *B. paratyphosus, dysenteriae,* and *pseudodysenteriae* by the same author (*Almquist*, 1908), with *B. coli* by *Kellerman* and *Scales* (1916), with *B. radicicola* by *Spratt* (1912), with *Proteus hominis capsulatus* by *Bordoni-Uffreduzzi* (1888*b*), with *V. cholerae* by *Hueppe* (1885), *Babes* (1889), *Nakanishi* (1901) and by *Almquist* (1904), with various other vibrios by *Firtsch* (1888), *Kohlbrugge* (1900) and by *Nakanishi* (1901), with spirochaets by *Noguchi* (1912 *d*), with diptheroid organism by *Nakanishi* (1900*c*) and by *E. de Negri* (1916), with *B. leprae* by *Czaplewski* (1898) and by *Meirowsky* (1914*b*), with *B. tuberculosis* by *Rosenblat* (1905) and by *Meirowsky* (1914*b*). The pictures made by the last-named author of *B. tuberculosis, leprae,* and *Spirillum rubrum,* which were reproduced as figures 164, 166, and 167 on Plate XII, as well as his drawings shown on Plate XIV in the column "Freie Knospen and Jugendformen," should be compared with some photographs made by *Kellerman* and *Scales* of germinating regenerative bodies of *B. coli,* reproduced as figures 199 and 200 on Plate XV. That two or three sprouts may break forth simultaneously, as demonstrated in the last-named picture, seems to be no rare occurrence. *Almquist* (1906) mentioned this fact in regard to *B. typhi,* and a photograph made by *Stamm* (1914), reproduced as figure 201 on Plate XV, illustrates the same type of growth with *V. cholerae.* The picture is of special interest, because it shows side by side with germinating regenerative bodies others, which evidently are developing to gonidangia.

The higher resistance of the regenerative bodies against heating, drying, and other unfavorable conditions has evidently exerted its influence where it was noticed that cultures of non-spore-forming bacteria sometimes exhibit a quite considerable resistance. Details in this direction have been repeatedly collected, e. g., by *Ficker* (1898), *Rothert* (1902), *P. Eisenberg* (1908), *Lehmann* and *Neumann* (1912), and by *Bernhardt* (1915). Own experiments with *V. cholerae*

furnished the first-named author the following interesting data. Cultures of different age died, when kept in the humid chamber at 37° C, after 1½, or after more than 50 days in the following succession:

	Days.	Days.	Days.	Days.
Age of the cultures	1	2	3	8
Duration of life	1½	3	14	More than 50

Microscopic studies apparently have not been made in this case, though older observations by *Firtsch* (1888) and by *Weibel* (1888) upon the increased resistance of the globular bodies present in old cultures of other vibrios should have suggested such investigations. *Firtsch* had noticed that the vegetative cells of *V. proteus* died when dried more than ¼–½ hour above sulphuric acid, while their "granules" still germinated after having been dried for 12½ hours; and *Weibel* had found that the "spores" of his *V. saprophiles* withstood the influence of moist heat of 53° C. for more than 24 hours. *Cantacuzène* (1898) reported that the round forms of *V. cholerae* were killed only by temperatures higher than 80° C., and *Almquist* (1916) succeeded by heating cholera cultures up to 60° C. in obtaining a strain, which for two years grew constantly in the round form, but still showed regular agglutination.

Gage (1903) noticed that most cells of *B. coli* and *typhosus* were killed by temperatures of 45–55° C., while some, however, withstood heating up to 85° C. Freezing acted in an analogous manner upon cultures of *B. typhosus*, *campestris*, and others, when tested by *E. F. Smith* and *Swingle* (1905); the authors suppose that "arthrospores" were present in their cultures. Many round and irregular forms were seen by *Preisz* (1904) in the secondary colonies, developing in old cultures of numerous bacteria, which also showed a considerable increase in longevity. *Spratt* (1912) reported that the round regenerative bodies of *B. radicicola* were even not killed by boiling water, and *Rodella* (1908) made use of the higher resistance of the analogous organs of the lactobacilli for isolating them: he inoculated material 4–5 days old into melted agar kept at 80° C. and left it therein for 2–3 minutes before lowering the temperature.

With diptheroid organisms similar results have been recorded by *A. Neisser* (1888), whose *B. xerosis* in 6-days-old cultures withstood 70° C. for 15 minutes, by *E. Klein* (1900), whose *Bacterium diptheroides* died usually within one week, but lived for many weeks in serum, where it regularly produced oval or spherical cells instead of the normal rods. The Corynebacterium studied by *E. de Negri* (1916) was also killed at 60° C. within one hour, when tested in the rod form, while the budding round cells remained alive. The round deeply staining bodies produced by *Streptobacillus pellagrae* resisted 80° C., according to *Tizzoni* and *Angelis* (1913). *B. mallei* showed only low resistance when tested by *Marx* (1899), but *Bonâme*, according to *Lehmann* and *Neumann* (1912, p. 548), found that occasionally a temperature of 70° C. was endured for 6 hours and that of 90° C. for 3 minutes. *Carpano* (1913) considered the round deeply staining "spores" of the glanders bacillus to be the reason of its remaining alive in the cultures for more than a year. *Schütze* (1908) noticed that the regenerative bodies ("spores") of *Actinomyces monosporus* endured the temperature of 75° C. for 40 minutes.

Sometimes the reproductive organs growing at the side or at the end of the bacteria do not show the characteristic appearance of the normal deeply staining regenerative bodies, but assume more the character of the endospores, especially with regard to their resistance against the ordinary staining methods. On account of their external position we call such bodies exospores. Our photographs of *B. subtilis*, reproduced as figure 197 on Plate XV, and of *B. Azotobacter*, figure 69 on Plate VI, may illustrate this occurence. The simultaneous production of endo- and exospores in the latter case is of special interest. On the other hand, the replacement of deeply staining regenerative bodies by unstained exospores, as shown with *B. subtilis*, seems to be very frequent with spirilla and vibrios. It is not improbable that the so-called arthrospores of *V. cholerae*, described by *Hueppe* (1885), *Babes* (1889), and others, have been, partially at least, exospores. *Weibel* (1888) observed with his different vibrios side by side stained and unstained round bodies, just as we did recently with some salt-water spirilla (*Löhnis* and *Smith*, 1916 *a*). Of his *Spirobacillus Cienkowskii Metchnikoff* (1889) made the drawing reproduced as figure 73 on Plate P (from original fig. 14 on Pl. 1). *Spirillum monospora*, described by *Dobell* (1908), seems to have exhibited a similar appearance. The spore-forming anaerobic

cellulose destroying bacteria, studied by *Prażmowski* (1880) and by *Omelianski* (1902), are another example to be mentioned here. As they are often curved, the first-named author used the old name Vibrio Rugula for them, but probably they should be better placed in the neighborhood of *B. oedematis maligni*. His drawings, showing the terminal spore formation, have been reproduced as figure 28 on Plate H. *Omelianski's* photographs seem to indicate that also in his preparations some of the terminal bodies took the stain, and apparently some lateral regenerative bodies were present, too. In addition his findings concerning the heat resistance of these spores deserves our attention; they withstood 95°, but died quickly at 100° C. It is true that the terminal spores of *B. tetani* and related anaerobic bacilli are characterized by a similarly low resistance. But it is a disputable point whether it is altogether correct to class them as endospores, as is usually done. In my opinion, they too should be accepted as exospores. Their position, forms, and degree of resistance links them obviously more closely to those exospores mentioned above than to the centrally located, highly resistant endospores, formed by the bacilli of the Subtilis-Mesentericus group.

Exospores are also produced occasionally by many other bacteria. *Lutz* (1886) noticed that *B. leprae* sometimes furnishes such bodies. With *B. tuberculosis* terminal spores were recorded by *F. Fischel* (1893), *Hawthorn* (1903 *b*), and by *Wherry* (1913), with *B. pseudo-diphtheriae* by *Simoni* (1898); in the latter case they survived 80° C for more than 10 minutes. Probably those spores of *B. tuberculosis* and *diphtheriae*, which according to the observations made by *Marpmann* (1893) and by *Babes* (see *Cornil* and *Babes*, 1890, Vol. II, p. 59), respectively, were even not killed by boiling, are also to be classed here.

Furthermore, the following so-called nonspore-forming bacteria have shown themselves to be able, under conditions not yet well known, to assume the faculty to produce fairly resisttant exospores (or, as they have been usually called, polar endospores). They are *B. acidi lactici* and *B. cyanogenes* (*Hueppe* (1884), *B. typhi* (*Gaffky*, 1884), *B. coli* (*Piccoli*, 1896), *Bact. lactis acidi* (*Weigmann*, 1899) and *Bact. Zopfii* (*Swellengrebel*, 1904). It has been mentioned on page 95 that some of these observations, especially with regard to typhoid and lactic acid bacilli, have been repeatedly refuted. Nevertheless, they, too, deserve a renewed study. That in all these cases invariably, and in most of them quite independently, polar spores have been found, is certainly not without importance. On the other hand, some spore-forming bacilli have been described, showing polar spores, too, whose general character brings them very close to usually nonspore-forming bacteria. These are: *B. esterificans Maassen* (1899), closely related to *B. coli; B. violarius acetonicus Bréaudat* (1906), evidently a spore-forming strain of *Bact. violaceum;* and an unnamed morphologically tetanus-like bacillus, growing yellow or red (*Morgenthaler*, 1916), just like *Bact. herbicola*. A closer search among the thousands of species descriptions would undoubtedly furnish more such evidence. But it is of much greater interest, that also the so-called denatured butyric acid bacilli, which have lost their ability to produce normal endospores, which, however, by certain methods can be induced to turn again to sporulation, were found by *Grassberger* and *Schattenfroh* (1907) to form round polar spores, like *B. tetani*. On the other hand, an old weakened culture of *B. anthracis* has been studied by *Chauveau* and *Phisalix* (1895), which had lost its faculty to produce endospores, but instead of these formed quite constantly terminal round bodies, which, however, were killed by temperatures above 70° C., and which could be stained by aqueous dyes, i. e., they were normal round regenerative bodies.

My own findings with Azotobacter and various other usually nonspore-forming bacteria are in full agreement with all these observations. It seems as if the production of terminal round regenerative bodies and of exospores is a necessary step which has to be passed when the formation of endospores is to be developed. Some genera (Spirillum, Vibrio) seem to be unable to reach the latter stage, but in regard to the so-called nonspore-forming rods it will be well worth trying whether or not the newly won insight will open experimental possibilities, which so far never have been tried. A few additional remarks upon this problem will be made on the following pages.

(3) ENDOSPORES.

Formation of endospores may occur within the vegetative rods, as well as within gonidangia and regenerative bodies. Thus far only the first possibility has been studied more thoroughly. According to *Zopf* (1883, p. 66) the granules first visible within the cell unite in making up the spore, but *L. Klein* (1889) studied some species which did not show any granulation of the cell plasma preceding the formation of the spore. As *Hueppe* (1891, p. 29) pointed out, either the whole content of the cell or only a part of it may be used up for that purpose. *Bunge* (1895) accepted only a special class of cell granules as the true elements of spore formation; others, like those seen by *P. Ernst*, were declared to be in no way connected with it. That, however, here as in other cases staining reactions are not very conclusive is clearly indicated by some results recorded by *Zettnow* (1899), who saw the spores, when they were treated with Romanowsky's method, turn red or blue or remain unstained, sometimes only showing a blue spot in the center. *Nakanishi* (1900 *a* and *b*) declared that the endospore be nothing else than a changed nucleus, but he soon modified this statement, saying that the nucleus surrounds itself with chromophilic cytoplasm and so becomes a spore. The spore formation of the large *B. Bütschlii* and *sporonema* was accepted by *Schaudinn* (1902–1903) as some primitive sexual process, to which reference will be made in Chapter IV. The granules present in the cell were seen to increase in number and in size before the spores were formed. *Růžička* (1909) defined spore formation as concentration of the chromatin substance of the cell; later, however, he was of the opinion that the chromatin center "vanish" in old spores. With *Bac. anthracis Péneau* (1911) observed that young cells appeared fairly homogeneous with only some small granules present, which after about 12 hours formed one definite nucleus; this in its turn, about 8 hours later, dissolved into a chromidial system, which ultimately, in the 3–4 days old culture, concentrated itself again, now making the spore. *Swellengrebel* (1913) saw that in his *B. deliensis* the chromatin granules arranged themselves first into straight centrally located or into zigzag filaments, which then in part and under assistance of part of the cytoplasm formed the spore, while the "vegetative" plasma and chromatin, thus separated from the "generative" plasma and chromatin, later dissolves with the rest of the cell. The unequal and in most cases unstable distribution of the nuclear material within the bacterial cell, which has been discussed on page 109, makes all these more or less divergent findings concerning spore formation quite comprehensible.

Occurrence of two endospores within one cell has been recorded by *A. Koch* (1888) for *B. inflatus* and *ventriculus*, and by *Vuillemin* (1903) for *Clostridium disporum*. The spore-forming cells in these cases have been all more or less inflated. The last-named author dwells upon this point, reaching the conclusion that spores formed under such conditions should be differentiated from the normal endospores as "cystospores," and the sporulating inflated cell should be called accordingly "sporocyst." That this point of view was fairly correct is proved by the fact that double and multiple spore formation may be shown by regenerative bodies, as well as by those inflated globular, pear- or club-shaped cells, which normally act as gonidangia. As it is fundamentally the same nuclear material, which, in the form of gonidia, regenerative bodies, exo- or endospores, serves the one purpose of reproduction, it is by no means surprising, that one type of reproductive organ may replace or may pass over into another, especially when we keep in mind that all these separations and classifications are much more artificial than natural. The photographs reproduced as figures 57 on Plate V, 65 on Plate VI and 117–121 on Plate X, showing the apparent or real beginning of spore formation within irregular cells (so-called involution forms, i. e. regenerative bodies and gonidangia) of *B. anthracis* (*Matzuschita*, 1900), *B. subtilis* (*Löhnis* and *Smith* 1916 *a*), *B. Chauvoei* (*Fraenkel* and *Pfeiffer*, 1895), *B. pestis* and *lactis aerogenes* (*Maassen*, 1904), *Proteus vulgaris* (*Hauser*, 1885) and of *V. cholerae* (*Maassen*, 1904), deserve to be studied closely, as they are very suggestive for further investigations along these lines.

A. Fischer (1891, 1903, p. 39), as well as *Migula* (1897, Vol. I, p. 166), were of the opinion that the co-called nonspore-forming bacteria would be eventually found to be able to produce endospores, too; to the first-named author this fact was "beyond doubt." His suggestion that

increased salt content of the substrate will be favorable in this direction, seems to be correct, as was discussed on page 99. And, as far as the nonspore-forming rods come into view, it is indeed probable that they can be induced to form regular endospores or to show themselves to be parts of the life cycles of spore-forming bacilli. With micro- and streptococci, spirilla, spirochaets, and mycobacteria, however, the situation seems to be different. In addition to what has been said above (p. 137) concerning the beginning of spore formation by so-called nonspore-forming rods, it may be pointed out that formation of spores has also been recorded with lactobacilli by *C. Sternberg* (1898) and by *Fokker* (1901), with *B. piscicidus*, a member of the Proteus group, by *N. Sieber* (1895), with members of the Coli-Aerogenes group by *Rogers, Clark* and *Davis* (1914), as well as by *Burton* and *Rettger* (1917), and with *B. fluorescens* by *Tanner* (1918). Microscopic and cultural characters showed otherwise little or no alterations in these cases; similarly, the small monotrichous *Bac. leguminiperdus*, described by *Oven* (1906), displayed much more the appearance of a common "Pseudomonas" than that of an endospore-forming rod. The situation becomes more complicated when the establishment of the ability to form endospores is accompanied by profound changes in morphology and cultural behavior of the organism. Yet this is to be expected and perhaps the rule in all those cases, where genuine endospores are developed, not only those polar "exospores", which stand between regenerative bodies and true endospores. When *Noguchi* (1910) transformed experimentally the anaerobic nonspore-forming *B. bifidus* into an aerobic bacillus closely resembling *B. mesentericus fuscus*, the ever-ready "contamination" theory was eliminated by the fact that the process could be reverted at will. Our own observations are in complete agreement with these findings. There are evidently clearly defined subcycles within the life cycles of the bacilli, which are not only characterized by the absence or presence of endospore formation, but by numerous other differences, too, which fact has thus far practically always misled to the assumption that two or more different species had to be separated, because a close study of the link connecting the different subcycles, viz., of the symplasm, has never been recommended before.

The observations made with cultures of otherwise endospore-forming bacilli, which have lost this ability are of special interest in connection with the facts just mentioned. *Grassberger* and *Schattenfroh* (1907) and many other investigators have noticed that anaerobic butyric acid bacilli not infrequently turn over into quite different aerobic nonspore-forming rods, which, like the asporogenous strains of the Anthrax-Subtilis-Mesentericus group, are microscopically, as well as culturally, much more similar to *B. coli* or *aerogenes* or to some lactobacillus than to their own sporulating parent organism. Sometimes they may also exhibit a more or less Actinomyces-like growth, as was obtained, for instance, from *B. anthracis* by *Nadson* and *Adamovič* (1912), as well as by *Henri* (1914). Of course, there is also the possibility merely to suppress the spore formation temporarily without otherwise changing the character of a strain to any considerable extent, as is often easily performed, e. g., by keeping the bacilli in milk; but this case should not be confounded with the real transformation of a strain, which change is always accompanied by more or less fundamental, morphological, as well as physiological, alterations, such as were observed, for instance, by *Winogradsky* (1902), *Passini* (1905), *Grassberger* (1905), and *Grassberger* and *Schattenfroh* (1907).

When the accidental loss of spore formation was studied for the first time by *Lehmann* (1887), it was found that instead of the regular endospores only "micro-spores" were produced, which, however, were killed when kept for 2–3 hours at 60° C. This observation was soon confirmed by *Roux* (1890) and others. More recently *Růžička* (1908–1909) paid special attention to these "sporoids," which he often found enclosed in large, hypertrophic cells. The same occurrence, i. e., the replacement of endospore formation by the development of gonidangia, has been already reported by *Weibel* in 1888 in regard to asporogenous anthrax bacilli, and by *E. Klein* in 1899 as a result of his studies upon *B. cadaveris sporogenes*; though, again, in the opinion of the latter author, these giant cells were "probably involution forms." *P. Eisenberg* (1908) noticed that asporogenous strains of *B. anthracis*, *tumescens*, *Megaterium*, and *ramosus* occasionally may exhibit a comparatively high resistance; a temperature of 90° C. was endured in his experiments for 5–15 minutes. He assumes that the capsules of *B. anthracis*,

and in the other cases "Ausnahme-Zellen," are to be made responsible for this result. That the latter have been regenerative bodies is very probable. According to *Garbowski* (1907*b*) the secondary colonies of *B. luteus sporogenes Smith* et *Baker* produced, instead of endospores, irregular forms, which were declared to be vegetative cells, but which evidently also have been in reality gonidangia and regenerative bodies. This conclusion is supported by the fact that *Preisz* (1904) found the irregular, mostly round or pear-shaped cells, present in the secondary colonies of otherwise spore-forming bacilli, to be fairly resistant; and earlier findings by *Chauveau* and *Phisalix* (1895), as well as *Henri's* more recent observations, leave no doubt that true regenerative bodies may be produced in large numbers by asporogenous strains of endospore-forming bacilli. Furthermore, it has been ascertained by *Olsen* (1897), *Cozzolino* (1900), and by *Peklo* (1910) that club-shaped cells may produce one endospore each, instead of becoming normal gonidangia. All these facts together may serve as additional evidence concerning the close relationship existing between gonidia, regenerative bodies and endospores, and in regard to the possibility of mutual replacement in the one or in the other direction. How the resistance gradually increases, when gonidia and regenerative bodies revert again to endospores, has been already studied to some extent by *Phisalix* (1892). Addition of blood to broth cultures of an asporogenous Anthrax strain was found to be very useful for promoting this process, but just as the bright "pseudospores" (gonidia) were quickly killed at 65° C., so the first new spores also withstood this comparatively low temperature only for a few minutes. Later, however, the usual high resistance was regained.

That the form and also the resistance of the endospores is by no means so constant, as is assumed by some authors needs hardly to be emphasized. With regard to anaerobic bacilli these facts have been made clear by *Hibler* (1908), but the same holds true with the aerobic bacilli. An average or "typical" form and resistance may, of course, be calculated; these, however, are again more or less dependent on the conditions of the experiment. That the resistance of the round terminal spores of the Tetanus-Putrificus group is generally distinctly lower than that of the regular oval endospores, as produced by *Bac. mesentericus, subtilis*, etc., and that, in addition, "failures" are much more frequent with the former than with the latter, once more confirms our view that such terminal spores should be better separated from the endospores, and find their place as exospores between regenerative bodies and endospores.

The germination of the endospores has also been accepted as being quite constant, and has been used accordingly by some authors, like *Migula*, as a means of classifying the spore-forming bacilli. That this assumption was not correct, and *Migula's* procedure therefore not well founded, has been shown by *Caspary* (1902). The same holds true, of course, with regard to such minor details, as the presence or absence of a special membranous capsule around the spore, to which occurrence great importance has been attached in the case of Clostridium Pastorianum and related forms of the Amylobacter group. The careful studies of *Bredemann* (1909) have decided this question.

That endospores sometimes may germinate while still enclosed within the parent cell, as was observed, e. g., by *Garbowski* (1907*b*) with *B. asterosporus*, furnishes an interesting counterpart to the analogous upgrowth of the gonidia retained within the parent cell or gonidangium, as was discussed on page 128.

Not only the mode of germination of the endospores, but the fact itself is by no means so constant as is often presumed. Many endospores not only refuse to germinate when tested, they even dissolve entirely and pass over into the symplastic stage, just as is done by many gonidia and regenerative bodies (see Chap. III). Whether they are also able to multiply by budding or by fission has never been studied, and the mere assumption that such a case might be possible is quite liable to be rejected as simply absurd by the well-established bacteriological dogmatism. However, as the complete dissolution of these apparently very solid forms is not difficult to ascertain, so it is also to be expected that positive results may be secured occasionally in the last-named direction. I have often seen round darkly staining buds attached to liberated endospores, looking exactly like the regenerative bodies growing at the side or at the end of the vegetative cells. The sprouting of young exospores from Azotobacter cells

containing at the same time endospores, as shown in figure 69 on Plate VI, is another fact to be kept in mind in this connection. *Maher* (1915) speaks of a breaking up of Subtilis spores into "cocci" or "vital granules," and as early as in 1878 it was reported by *Ewart*, that he saw what he calls Anthrax "spores" divide themselves into 2 and 4 parts, while others germinated directly. It is more probable, as was said on page 93, that these spore-like bodies, which have also been observed by *E. Klein* (1883) and more recently by *Růžička* (1908), have been regenerative bodies or microcysts. Nevertheless, they also might be considered to have been rudimentary endospores, still showing some of the features characteristic for the less resistant reproductive organs. It is likewise to be admitted, that not the well developed "ripe" endospores are inclined to enter the symplastic stage, but that this is more a kind of subterfuge for rather weak endospores, which otherwise would be complete "failures."

(4) ARTHROSPORES AND MICROCYSTS.

The formation of arthrospores, i. e., the segmentation of the vegetative bacterial cell and the transformation of these segments into fairly resistant reproductive organs, seems to have been first observed by *Van Tieghem* (1879*b*) with a spirochaete found in oysters. Soon after *Zopf* (1881) and later *W. H. Hoffmann* (1912), as well as *Gross* (1912), reported upon similar findings. Some characteristic drawings made by the last-named author have been reproduced as figure 63 on Plate O. *Kurth* (1883) studied the same process with *B. Zopfii*, where he saw each rod produce two arthrospores. *Hueppe* (1885), who like *DeBary* (1884) believed the formation of arthrospores to be very widespread among the bacteria, also accepted the breaking up of the rods into coccoid resistant bodies as the characteristic feature of this process. Both authors, however, have used the term in a rather loose manner; regenerative bodies, as well as microcysts, have also been called by them arthrospores. The same holds true with regard to *Zopf* (1892), who ascribed, for instance, arthrospores to his *Bact. vernicosum*, merely because he observed a slightly increased resistance, which, of course, may just as well have been due to the presence of regenerative bodies. A good example of typical arthrospore formation has been contributed by *Matzuschita* (1902), when he described his protean bacillus from air. His drawings, reproduced as figure 5 on Plate B, show clearly side by side formation of gonidia and their upgrowth within the gonidangia, the presence of lateral regenerative bodies, the production of arthrospores, and the transformation of whole cells into microcysts. Most regular and characteristic, however, is the arthrospore formation with the Actinomycetes. *Gasperini* (1889), *Domec* (1892), *Kedzior* (1896), *Doepke* (1902), *E. Levy* (1902), *Gilbert* (1904), *Lehmann* and *Neumann* (1912, p. 622) have furnished descriptions of this process. Most typical is the dividing up of the short side branches of aerial hyphae into the coccoid spores, sometimes also called conidia, in accordance with mycological nomenclature. In the long threads the development of reproductive organs often stops with the formation of the gonidia, which then slip out, leaving the empty sheath behind them. This is still more frequently the case with the Mycobacteriaceae (see p. 124). Some of the papers upon tubercle bacilli, however, also contain reports on genuine arthrospore formation. And the slight differences recorded by the numerous authors dealing with "fragments," "spores," and "granules" of the tubercle bacilli, are undoubtedly caused in part by the fact that, on account of incomplete observations upon the manner in which these bodies were formed, it could not be ascertained exactly whether the round forms seen and tested have been gonidia or regenerative bodies or arthrospores.

The round thick-walled resting cells of the genus Myxococcus have also been repeatedly called arthrospores. But as most authors who studied the subject have reported that the whole cell contracts itself, forming one resting body, the term microcysts seems to be preferable. It is true that it has been observed in some cases, for instance by *Krujff* (1908), that the rods first divide themselves, and it is to be admitted, as was said on page 123, that such occurrences may be also considered to represent arthrospore formation, but it seems best to place them in an intermediate position, connecting arthrospores and microcysts.

The form of the arthrospores is, according to their mode of formation, not always exactly spherical or ovoid, but more of cubical shape, and as the thickening of the cell wall is most

characteristic for this process, the staining reaction does not show any, or at least not much, alteration, compared with that of the vegetative cells.

Germination of the arthrospores of spirochaets has been studied first by *Van Tieghem* in 1879, while more recently *Gross* (1912–1913), as well as *W. H. Hoffmann* (1912), were unable to observe this process again. Positive results have been also recorded by *Kurth* (1883) with his *B. Zopfii*, and by *Gasperini* (1889), *Domec* (1892), *Lachner-Sandoval* (1898), *Feistmantel* (1902), *E. Levy* (1902), *Gilbert* (1904), and others in regard to Actinomycetes. These findings invalidate a statement made by *Jordan* (1909), p. 407; 1916, p. 463), that the coccoid bodies produced by Actinomycetes are not "in anywise related to the normal reproduction of the species." Not infrequently two to four young threads break forth simultaneously, creating a picture very similar to that shown of *B. coli* in figure 200 on Plate XV. The membrane of the germinating arthrospore seems to be used again, if not always so, at least in most cases.

Multiplication as such has been never recorded with genuine arthrospores.

The resistance of arthrospores has been always found to be much greater against drying than against heating, although in this direction again fully developed arthrospores are clearly more resistant than vegetative cells. According to *Kurth* (1883) the dried rods of *B. Zopfii* died after 5–7, the arthrospores after 17–26 days, but heating experiments revealed no difference. Abnormally high resistance was recorded by *Kedzior* (1896) for a thermophilic actinomyces, whose spores are said to have withstood 100° C. (steam) for 3½–4 hours. *Neukirch* (1902) found 5 minutes at 70° C. to be the limit; *Feistmantel* (1902) fixed the death point for spores of "Streptothrix farcinica" at 60° C. for 15 minutes. *MacCallum* (1902) noticed that young cultures of *Actinomyces asteroides* were killed at 65° C. within 5 minutes, while older ones endured 65° for 30, 68° for 5–10 minutes. The vegetative cells of *Actinomyces thermophilus* died according to *Gilbert* (1904) at 65° within 5 minutes, but the spores withstood 70° C. for more than an hour. Old dry cultures of *Actinomyces violaceus*, grown on straw and practically completely transformed into spores, were found by *Berestneff* (1907) to be still alive after more than 10 years. *Lehmann* and *Neumann* (1912, p. 623) state that vegetative cells of Actinomycetes are killed at 60–65° C., whereas the arthrospores endure 75–85° C. for 5 or 3 minutes.

The formation of a microcyst, i. e., the transformation of a whole vegetative cell into one usually relatively large resting body, is characterized in most cases by a swelling up and rounding of the cell, followed by a more or less considerable thickening of the cell wall. With the curved forms, especially with spirochaets, a coiling up of the body initiates the process. Microcyst formation seems to have been first seen with Streptococci. As early as in 1876 *Salomonsen* reported that Streptococci, which otherwise did not produce resistant cells, furnished great numbers of them when kept in blood at 40° C. Soon afterwards *Van Tieghem* (1879*c*) published his first illustrated description of *Leuconostoc mesenterioides*, whose "spores" were shown to be analogous to the heterocysts of the Nostocaceae, in which group of organisms Leuconostoc itself was later placed by *Van Tieghem* (1884, p. 1108). Its "spores" were now called "kystes." When studying his *Micrococcus ochroleucus*, *Prove* (1887) noticed that the cells, whose normal diameter was 0.5–0.8μ, sometimes increased to 1.6–1.8μ diameter and became more resistant against heating, as well as against staining. Some of the large dark cells visible in our photographs of *Streptococcus lactis* (Plate I, fig. 11) and of *Sarcina flava* (Plate II, fig. 15) look very much as if they had also been microcysts, but no special tests upon germination and increased resistance have been made so far. The drawings of the acetic acid bacteria, made by *E. Chr. Hansen* (1879), show within the chains some large thick-walled cells, which *Hansen* considered to be possibly "spores." (See fig. 15 on Pl. E.) Likewise, the pictures of the "proteusartige Luftbacillus," drawn by *Matzuschita* (1902; see fig. 5 on Pl. B), leave hardly any doubt that microcysts were also formed by this species. An excellent illustration of the same process, as seen with spore-forming bacilli, has been furnished by *A. Meyer* (1901); it was reproduced as figure 64 on Plate O. The drawing made by *E. Klein* (1883) of the round forms of *B. anthracis*, which has been shown as figure 21 on Plate F, furnishes an interesting counterpart. The thick-walled large cells of Azotobacter are equally typical microcysts. *H. Fischer* (1905), *Krzemieniewski* (1908), and especially *Prazmowski* (1912, p. 162) have studied them fairly thoroughly.

Vibrio proteus has been seen by *Firtsch* (1888) to coil up occasionally, as it is rather frequent with spirochaets, according to the observations made by *Breinl* and *Kinghorn* (1906), *Prowazek* (1906*b*, 1907*a*), *Breinl* (1907), *Schaudinn* (1907), *Gonder* (1909), *Karwacki* (1911), *Wolbach* and *Binger* (1914), *Inada* et al. (1916), and others. Unquestionably not all of these coiled forms develop actually to regular microcysts. The drawings made by *Prowazek* (1907*a*, original fig. 8*b*), which are reproduced as figure 74 on Plate P may illustrate this possibility, while some other sketches, published by *Inada* and his collaborators (1916, original figs. 71 and 72) and reproduced as figure 75 on Plate P, probably are to be accepted as showing the formation of genuine microcysts.

Germination of microcysts has been recorded with those produced by cocci and by Azotobacter. *Van Tieghem* (1879*c*, 1884) saw that the "kystes" of Leuconostoc when still inclosed in the chain germinated laterally and the membranes of the microcysts were left behind by the young cocci. The analogous behavior of the heterocysts of Nostoc and of other Cyanophyceae has been described by *Brand* (1901). Germination of the microcysts of Micrococcus ochroleucus has been observed by *Prove* (1887). *H. Fischer* (1905) reported that the germinating Azotobacter left no empty membrane behind, but *Krzemieniewski* (1908), *Prazmowski* (1912), and *D. H. Jones* (1913) recorded opposite results.

In the same manner as some of the vegetative cells increase in size and become gonidangia, so also microcysts may occasionally undergo a similar change, and they, too, may either liberate a number of gonidia, or these may reproduce new vegetative cells while still inclosed within the microcyst. The liberation of the gonidia seems to be the rule with the microcysts of spirochaets (*Breinl*, 1907); direct germination apparently never has been observed in this case. The microcysts of streptococci not infrequently break up into 3 or 4 parts, each of them acting as a new vegetative cell. *Babes* (1908) probably was the first to give an account of this interesting occurrence. If such a cyst remains within the chain, it may act as a very conspicuous starting point for branches, as was noticed by *Vincent* (1902). The early report of *E. Klein* (1883) upon what has been at least in part microcysts of *B. anthracis* also refers to their dividing into 2, 3, or 4 parts, each of which proved to be able either to multiply as a round budding vegetative cell, or to grow up again to a normal rod. The drawings made by *Matzuschita* (1902) from his protean bacillus from air, reproduced as figure 5 on Plate B, shows also some large round cells, looking like microcysts, which clearly exhibit the same mode of fission. More recently *Hort* (1917*b*) noticed that the "giant cells" of Meningococcus may either become gonidangia or divide themselves into 3 or 4 equal parts.

Concerning the resistance of the microcysts very little is known at present. Similar to the arthrospores, they are evidently more apt to withstand the influence of drying than that of heating. However, in a few cases *Prove* (1887) was able to record a surprisingly high resistance; some of the microcysts tested by him are said to have endured 100° C. for more than one-half hour. *Baumgarten* (1890, p. 295) mentioned that old cultures of staphylococci were not always killed, when kept at 99° C. for 15 minutes, and *A. C. Abbott* (1912) succeeded in selecting especially vigorous strains of *Staphylococcus aureus* by keeping the original culture for 5–20 minutes in fairly strong antiseptic solutions (0.1 per cent $HgCl_2$, 0.75 per cent phenol or saturated Na_2CO_3). *Holman* (1914) noticed that in one case streptococci were not even killed when kept three times for 20 minutes in the Arnold apparatus, a result which evidently must be attributed to the presence of protecting albuminous substances in the substrate. Special experiments upon the heat resistance of the microcysts of Azotobacter, *Bac. anthracis* and of related species apparently have not been made so far. A rather considerable resistance against drying, however, has been repeatedly observed with the first-named organism.

(*d*) GONIDIA AND FILTERABLE VIRA (CELL INCLUSIONS, APHANOZOA, ETC). GONIDIA AND HETEROGENESIS.

The size of the bacterial gonidia shows wide variations, especially when they have grown within a gonidangium. With the smaller species the diameter is usually 0.1–0.3 μ. Therefore, a more or less considerable number of gonidia is able to pass Chamberland, Berkefeldt, and similar bacteria filters, and when transferred to a suitable medium, such a filtrate, though freed

from all bacteria, may still cause an effect on account of the gonidia present therein. This possibility makes the filterable gonidia an important subject in connection with the study of filterable vira, certain cell inclusions, so-called aphanozoa, chlamydozoa, etc. Some of these may, indeed, belong to the protozoa; but there is no reason why the same assumption should be accepted as the only working hypothesis in all cases. In fact, several observations are already available, which make it certain that sometimes bacterial gonidia, too, may play an important part, and it is very probable that they will win in importance, as soon as more attention is centered upon this point.

General reviews of the whole subject have been published by *Prowazek* (1907), *Lipschütz* (1909), *Loeffler* (1911), *Doerr* (1911), *Wolbach* (1912), *Fontanel* (1913), and others. According to the first-named author the small bodies concerned are less than 0.25 μ in diameter, of globular shape, occurring singly, in pairs, in chains or small clumps, difficult to stain, usually best with *Giemsa's* method, and fairly resistant against physical and chemical effects. In addition *Fontanel* has pointed out that they are probably all motile. All these characters would fit the filterable bacterial gonidia: size, shape, motility, staining qualities, as well as increased resistance, are the same. That especially glycerin is a good preservative for gonidia, as it is for filterable vira, has been already ascertained by *Neelsen* in 1880, and more recently by *Mathers* (1917). With regard to alcohol analogous results have been obtained by *Iwanowski* (1899).

The development within the cells of the host as "cell inclusions," "Kern-Kappen," etc., has been often assumed as indicating the protozoal nature of the intruders. But already in 1889 *MacFadyean* reported upon the interesting fact that the small "cocci" (gonidia) produced by Actinomyces invade the animal cell, sometimes even the nucleus, and develop therein. The gonidia of spirochaets were seen by *Balfour* (1911 *b*), *Ross* (1912), and others, to behave in the same manner. And *Dutschenko* (1914) was able to ascertain that smallest inclusions, found by him within the red blood cells of rodents, which they destroy, and which therefore at first were considered to be some protozoa related to Theileria parva, developed, after being liberated, in the blood to bacteria, similar to those of the plague.

That gonidia, and sometimes regenerative bodies, too, may occur within the mast cells, has been mentioned on page 111. As *Herzog* (1913) has pointed out, it still remains to be studied, whether the "eosinophilic" granules, which are present in blood cells, are actually cell products or bacterial gonidia. That the latter are much inclined to grow as such, and to replace the bacteria within the body, has been pointed out by *M. E. Abbott* (1900) and others. The fact, that thus far only in a few cases development of normal bacteria cells has been obtained from these filterable coccoid bodies, does not exclude the possibility that improved methods will secure positive results also in other cases. As far as filterable vira have been cultivated as such, their behavior did not differ from that shown by cultures of filterable gonidia.

The organisms of vaccine and variola, classed by *F. Cohn* (1872 *a* and *b*) somewhat prematurely as *Micrococcus vaccinae*, were declared by *Calkins* (1904) to belong to the Microsporidia; but all his findings can be just as well accepted as descriptions of bacterial gonidia, regenerative bodies, and symplasm. Distinctly more in favor of the protozoa hypothesis are the results obtained by *Howard* and *Perkins* (1904), while the various communications made by *Prowazek* (1905, 1906 *a*, 1907 *c*) upon "Initialkörper" and Chlamydozoen" leave the matter again entirely in doubt. The findings of *Bonhoff* (1905) upon what he called *Spirochaeta vaccinae*, seem never to have been followed up; they were very similar to results obtained in various spirochaetoses. That the causative agent is filterable has been shown by *Siegel* (1905 *a*) and by *A. Negri* (1906). The cultures made by *Siegel* (1911) of his *Cytorrhyctes vaccinae* would suggest relations to some Micrococcus. However, no conclusive results have been secured.

The various coccoid bodies found by *Nencki, Sieber* and *Wijnikewitsch* (1898) to be connected with "Rinderpest" also failed to exhibit any sign, which would be strictly against their bacterial nature.

The small motile globules first grown by *Nocard* and *Roux* (1898) from pleuropneumonia of cattle, seem to have been the gonidia of a pleomorphous bacterium, described by *Bordet* (1910), by *Borrel, Dujardin-Beaumetz, Jeantet,* and *Jouan* (1910) under the name *Asterococcus*

mycoides, and by *Martzinowski* (1911) as *Coccobacillus mycoides peripneumoniae*. Confirmative reports are still outstanding; and *Kallert* (1911) is of the opinion that colloidal substances from the serum have been mistaken for organisms.

After *Dorset, Bolton*, and *McBride* (1905) had ascertained that hog cholera is caused by a filterablev irus, *Lourens* (1907) showed that *Bact. cholerae suum* is able to produce filterable "granules," which were found to be able to reproduce the bacilli in the animal, but not in the cultures. They were, therefore, declared to be the primary, the bacilli the secondary cause of the disease. *Hübner* (1908) contested these observations strictly, as did *Uhlenhuth, Xylander, Hübner* and *Bohtz* (1908–1909), who confirmed and extended the findings of the American authors, not only with regard to hog cholera, but also concerning swine plague. The multiplication of the filterable virus as such was especially studied by *Pfeiler* and *Lentz* (1913). *Rüther* (1910), on the other hand, is of the opinion that the granules present in the infectious filtrate are produced by spirochaets, which were seen to be present in blood, urine, and in the organs of diseased, but not in healthy hogs. After 10 days they also reappeared in the filtered virus, and their reproduction from the filterable granules is reported to have been observed on solid substrates, too. The granules were found in great number in lice and intestinal parasites (nematodes and others), to which the author ascribes, therefore, an important rôle in transmitting the disease. Sometimes the spirochaets were seen to break up into small rods, looking like *B. septicaemiae* or *influenzae*. Very similar results have been obtained by *King* in cooperation with *Baeslack* and *Hoffmann* (1913) with a *Spirochaeta suis*, which again was found only in diseased hogs and was seen to break up into filterable infective granules. *Healy* and *Gott* (1916) were able to grow the filterable forms as such in 1 per cent glucose broth, to which ground mesenteric glands of hogs had been added, and *Proescher* and *Seil* (1917) described anew the small coccoid bodies present in endothelium cells, blood, and urine.

Trachoma, as well as blennorrhoea non gonorrhoica, are caused, according to *Halberstädter* and *Prowazek* (1909), by the Chlamydozoa discovered by them. As *Heymann* (1909) has pointed out, however, only the "Kern-Kappen" are to be considered of diagnostic value, while single and double granules were declared by him to be present in various affections of the conjunctiva. On the other hand, extended studies of this subject led *Herzog* (1910) to the conclusion, that the so-called trachoma bodies should not be connected with protozoa, but are formed by "micro-gonococci," which are produced by "macro-gonococci." *Böing* (1912) was not willing to accept any of these findings as being correct, and also *Noguchi* and *Cohen* (1913) at first were only able to isolate and cultivate anaerobically small coccoid bodies, whose cultures showed all stages of the so-called inclusions, but did not give definite results in inoculation experiments. *Herzog* (1913), however, furnished further proof concerning the rôle played by the minute "involution forms" (gonidia) of the gonococci; an interesting picture, presenting these smaller and larger, globular and dumb-bell-shaped bodies, has been reproduced as figure 202 on Plate XVI (from original fig. 5 on Pl. III). It should be compared with figure 2 on Plate A. The matter was brought beyond doubt by the extensive investigations made by *Williams, Wilson* and *Gurley* (1914). Trachoma inclusions are, according to these authors, "simply intracellular nests of growing bacteria"; besides the gonococcus a hemoglobinophilic bacillus was found to be able to produce in cultures, as well as in the eye, all forms described by *Prowazek*, especially "dense clumps of extremely minute and irregular coccoid forms." A second contribution by *Noguchi* and *Cohen* (1915 added some interesting data, suggesting analogous relations existing between the Koch-Weeks bacillus and cell inclusion conjunctivitis.

With regard to lyssa *Babes* (1907*c*) has pointed out that while the so-called Negri bodies are not always visible and probably represent merely cell products, very small granules, which stain like bacteria, are constantly present. *A. Negri* (1909), however, maintained, that the cell inclusions be parts of the life cycle of a protozoon, *Neurorrhyctes hydrophobiae*. The standpoint taken by *J. Koch* and *Rissling* (1910) is more that of the first-named author, and *S. R. Klein* (1911) reached the conclusion that rabies is to be considered as a very acute streptococcal infection, and the Negri bodies as remnants of these streptococci. Staining

experiments misled *Tanakamuru* (1913) to assume, the granules present in rabietic brain to be merely lipochrom and degeneration products of the gangliar cells. *Noguchi* (1913), as well as *Williams* (1913), were able to cultivate the virus as such. They both think that the bodies grown looked like protozoa, not like bacteria; but the photographs made would equally fit the appearance of bacterial gonidia and regenerative bodies.

From scarlatina filterable, motile granules have been obtained by *Siegel* (1905 *b*), who classes them as *Cytorrhyctes scarlatinae* among the protozoa, while *Bernhardt* (1911) has pointed out, that the cell inclusions visible are similar to those seen in trachoma, and this holds true also with regard to the fine filterable granules, which are often dumb-bell-shaped. That they may be the gonidia of the streptococci, which are always present as "secondary invasion" in scarlatina as in measles, has become very probable by *Hort's* studies (1915–1917).

Poliomyelitis is another case where it seems to be very probable that the filterable small bodies first obtained by *Flexner* and *Noguchi* (1913) are gonidia of streptococci. After they have become adapted to artificial substrates, they behave very much like small streptococci, according to the data furnished by *Flexner, Noguchi* and *Amoss* (1915). That, however, the small forms are, in fact, parts of the life cycle of a polymorphous Streptococcus, has been first proclaimed by *Rosenow, Towne* and *Wheeler* (1916), and it was soon afterwards confirmed by *Nuzum* and *Herzog* (1916). These, as well as the further contributions by *Rosenow* and *Towne* (1917), *Mathers* (1917), *Mathers* and *Howell* (1917), *Rosenow* and *Wheeler* (1918), *Rosenow, Towne* and *Hess* (1918), leave hardly any doubt that it is also in this case the filterable gonidia, which act as the specific virus. *Amoss* (1917), as well as *Bull* (1917), have contested *Rosenow's* and *Nuzum's* results, but their own experiments can not be accepted as convincing negative proof, especially when the peculiar staining reactions, as well as the characteristic cultural behavior, of the filterable gonidia are duly considered. *Rosenow* and *Towne* are undoubtedly right when they point out that the whole subject concerning the filterable vira needs a comprehensive study from these new standpoints.

The aphthe virus has been classed by *Siegel* (1905 *a*) as a *Cytorrhyctes aphtharum* in the neighborhood of *Cytorrhyctes vaccinae*, but later experiments (1910) led him to the belief that this Cytorrhyctes is a type of growth of a micrococcus. Further investigations (*Siegel*, 1912) strenghtened this view; his photographs are exactly of the same type as those made by *Rosenow, Nuzum* and by *Mathers* of the poliomyelitis germ. Pictures published by *Betegh* (1911) of what he considers to be the causative agent of foot-and-mouth disease, are very similar. *Siegel's* as well as *Betegh's* claims have been refuted by *Wehrle* and *Zwick* (1913) and by *Kallert* (1913). A reply was published by *Siegel* (1913). The problem needs further unbiased study, as was emphasized by *F. Winkler* (1906).

As causative agent of syphilis a *Cytorrhyctes luis* has been introduced by *Siegel* (1905 *c*), which was accepted by *Leuriaux* and *Geets* (1906) as the granular form of *Spirochaeta pallida*. The important rôle played by the gonidia in other spirochaetoses has been repeatedly emphasized. *Rüther's* and *King's* reports upon the granules of *Spirochaeta suis* were quoted above, those made by *Breinl* (1907) upon the filterable gonidia of *Spirochaeta Duttoni*, by *Balfour* (1911 *a* and *b*) upon *Spirochaeta granulosa*, and by others have been discussed on pages 105–106. *Wolbach* and *Binger* (1914) pointed out correctly that sometimes errors may be caused by spirochaets passing the filter, just as is done occasionally by other bacteria; but the first-named author's statement (*Wolbach*, 1915), "that there is no evidence of spirochaets multiplying by any other method than single fission," is not in accordance with certain observations, and that in his experiments the granules did not multiply as such, does not invalidate the fact, that under suitable conditions all bacterial gonidia act in this manner. *Balfour's* discovery concerning the higher resistance of the "infective granules" against salvarsan and the importance of this finding in regard to chronic spirochaetosis have been mentioned on page 131.

The widely varying observations upon typhus exanthematicus may be accepted as another instance where the study of the presence and action of bacterial gonidia will help solve the problem. The diplococcus, described by *Rabinowitsch* (1909), as well as the pleomorpho

organism isolated by *P. Th. Müller* (1913), whose pictures have been reproduced as figures 22–24 on Plate II, or the equally pleomorphic anaerobic bacillus discovered by *Plotz, Olitsky* and *Baehr* (1915), may all act either as such or by means of their gonidia. *Hort's* (1915–1916 *a*) experiments have already brought much light in this direction.

With meningitis the situation is quite similar. Here again, according to *Hort* (1916 *a*), the micrococci themselves are important as a "danger signal," that the true infective agent, their filterable gonidia, may be present. The fundamental importance of these meningitis investigations, made by *Hort* and his collaborators (1915–17), has been justly emphasized by *Adami* (1916), who also pointed out that besides to meningitis, typhus fever, scarlatina, and hog cholera the same principle may apply to tuberculosis. That, indeed, filterable gonidia are produced by *B. tuberculosis*, too, had been demonstrated already by *Fontes* (1910).

That in common colds once more filterable gonidia are of etiologic significance, is practically beyond doubt. The anaerobic organism isolated by *Tunnicliff* (1913–1915) from the nose, as well as *Micr. catarrhalis*, and perhaps other bacteria, too, again seem to be less important directly than indirectly by their producing infective, partially filterable gonidia. What *Kruse* (1914) named *Aphanozoum coryzae*, the virulent filtrate causing the cold, has been cultivated as such by *Foster, jr.* (1917). Morphology and staining reactions of the smaller and larger budding bodies, which the author compares with *Flexner's* globoid poliomyelitis germs, are exactly those of gonidia and of regenerative bodies.

That the virulence of the gonidia may be more or less different from that shown by the vegetative cells, from which they originate, is not surprising. Of equal interest, however, is the possibility, that distinctly antagonistic activities may be displayed by the parent cell and its reproductive organs. *Almquist* (1911) obtained, when studying the growth of filtered gonidia of *B. typhosus*, occasionally instead of the usual, very scant development, a thick yellowish layer on lactose agar, formed by small immotile oval forms, which were not pathogenic, but whose sera agglutinated the typhoid bacilli. That these peculiar organisms have been no contamination has become certain by further investigations made by *Almquist* (1917), which in no case gave an upgrowth of normal typhoid bacilli from the filtrate, while in 10 per cent of the tests the same "*Bact. antityphosum*" was obtained, which remained stable for 7 years, and which on account of its behavior in the agglutination and in the *Pfeiffer* test is believed to be a "mutation" of *B. typhosus*. *Herelle* (1917) also reports to have isolated from feces and urine of dysentery convalescents an "invisible" microbe of antagonistic character, which did not grow on any substrate, except in the presence of dysenteria bacilli killed and solved by heating. Similar results, though not quite so clear, were obtained by the same author in studies upon paratyphoid.

The possibility that all bacteria, perhaps with the only exception of the large trichobacteria, may produce filterable gonidia, makes the conclusion inevitable, that they must be present quite generally in nature, as well as in the laboratory. In fact, the omnipresence of "ultramicroscopic" germs of bacteria has been already considered by *Burdon-Sanderson* in 1871, and more recently by *Gaidukov* (1906); but this hypothesis has been refuted by *Molisch* (1908) and by *Cano* (1909). The former author points out that neither he nor anybody else had ever obtained cultures of "ultra-microörganisms," and the latter recorded nothing but negative results when he tested the filtrates of many different substances under the microscope, in cultures, or in the animal test. These negative findings, however, are by no means decisive. As is the case with the filterable vira, also the other, not pathogenic filterable gonidia produce in or on the substrates used in the laboratories—provided that they grow at all—such a very scant growth that it can be as easily overlooked as their presence under the microscope. The extremely thin and restricted dewy layer on solid media, or the very slight cloudiness in liquid substrates, seems to be all what can be expected. But as at least in some cases a renewed development of larger forms has been secured, it is to be expected that more positive results will be obtained, when the conditions allowing such upgrowth will be better known, and especially if the important rôle played also in this case by the symplastic stage, will receive adequate consideration. That positive results have been obtained more frequently within the animal than in cultures agrees well

with the fact that genuine plasma, not changed by heating, evidently greatly favors such upgrowth as is clearly indicated by the observations to be presently discussed.

The knowledge of the participation of the gonidia in the life history of the bacteria throws a very interesting light upon some facts, which have been accepted so far by several authors as stringent proof of the possibility of heterogenesis. It has been mentioned already (on p. 14) that some years ago *Dunbar* (1907), whose experience in doing bacteriological work can not be questioned, published a book wherein he gave many facts apparently proving that all kinds of bacteria may be produced by the same species of algae, and that this book was accepted by authors like *Pringsheim* as an attempt to undermine the whole science of bacteriology. If the general knowledge of the literature would be better as it usually is, it had at once become evident, that *Dunbar's* results are practically identical with those recorded by many earlier authors, who all found, that within dying or dead cells of algae, fungi or other organisms, bacteria may develop from smallest granules, which microscopically can not be distinguished from the cell granules themselves.

Dujardin (1841, p. 93) mentions that it has been the opinion of *Müller*, *Dumas*, *Gleichen*, and other authors, at the end of the eighteenth and at the beginning of the nineteenth century, that the organic residues of plant and animal life dissolve themselves into "globules élémentaires," which by transformation may become "infusoires." According to *Fokker* (1887 *a*, p. 3), *Buffon* and *Needham* assumed that the living molecules after the death of plants and animals may continue their existence as such and eventually build up new microörganisms. *Perty* (1852), *Pouchet* (1863), and *Trécul* (1865–1867) stood practically on the same heterogenetic standpoint, and the victory attained by *Pasteur* in regard to spontaneous generation had in fact not much influence in this direction. That life can not begin anew was soon generally admitted, but the theory of heterogenesis still found many defenders, and as long as the existence of the bacterial gonidia is not taken into account is, indeed, invincible.

The detailed description given by *Trécul* (1865–1867) of the upgrowth of Amylobacter within closed dead cells from very small granules, "les derniers molécules vivantes de protoplasma," fits remarkably well to the results recorded by *Dunbar*. The same holds true concerning the findings made by *Karsten* (1869) together with *Harz*, who by continuous direct microscopic observations ascertained that within cells of yeasts and of other fungi, but only when their vital activity had come to a standstill, "micro-gonidia" may develop, which later either internally or externally may grow up to "Vibrionen":

> Sehr überzeugend sieht man diese Entwicklungserscheinungen der endogenen Zellchen zuweilen an einzelnen Gliedzellen von Pilzmycelien, die zwischen andern, welche gesund verbleiben und sich normal entwickeln, erkranken (p. 29).

An interesting drawing made by *Karsten* (1869) is reproduced as figure 76 on Plate Q (from original fig. V). The development of small rod-like bacteria within a Rhizopus sporangium, and the upgrowth of various forms from the minute "micro-gonidia" is fairly well discernible.

The otherwise rather faulty observations made by *Hallier* (1866–1896) and by *Lüders* (1866) have been correct in so far as these authors, too, have watched directly the transformation of smallest granules within dead cells of fungi into bacteria, but it was, indeed, an astonishing logical mistake, when *Hallier* still in 1895 (p. V) tried to defend the following absurd conclusion:

> Die winzigen Zellbildungen, welche *Nägeli* unter dem Namen der Spaltpilze zu einer Familie zusammengestellt hat, sind keine vollständigen Gebilde, sondern Erzeugnisse des Plasma verschiedener Pilzgruppen. Die *Nägelische* Familie der Spaltpilze ist also aus dem System zu streichen.

The voluminous contributions made by *Bastian* (1872–1914) to the theory of heterogenesis become also quite interesting, when read with some knowledge of the existence and the behavior of the bacterial gonidia and, in addition, of the symplastic stage of bacterial life, as will be discussed in Chapter III. The "newly evolved specks of living matter" now lose at once their mysterious character.

The "microzymas" of *Béchamp* (1883) present a similar case. His drawing reproduced as figure 77 on Plate Q (from original fig. 4 on Pl. I) show formation and liberation of gonidia by

long rods about as clearly, as it was pictured, for instance, by *Billroth* in 1874 (see fig. 45 on Pl. L) or 40 years later by *Meirowsky*. (See Pl. XIV). It will be justly doubted, however, that *Béchamp* was right when he stated (p. 628):

> Les seuls éléments anatomiques non transitoires de l'organisme qui persistent après la mort et qui évoluent pour former des bactéries, sont les microzymas.

But in view of the observations mentioned above, it is already more easily to be understood, when he says (p. 143):

> . . . que les microzymas sont de ceux qui produisent aisément des bactéries.

And when he points out (p. 473) that the microzyma is not by itself a bacterium, but is related to it in the same manner as a spore to a mold, and (on p. 839) that the bacterium is able to produce again "microzymas" he evidently comes very close to the truth. That bacteria easily develop from the "microzymas" in dead plant cells, blood corpuscles or fibrine, while other substances, for instance the white of the egg, did not give such a "transformation," is also in full agreement with the findings of other investigators.

Engler (1882) reported, that he not infrequently saw small bacteria develop within dying cells of a large Beggiatoa, though he did not assert, of course, as did *Wigand* (1884), that they were formed there by "anamorphosis" of the cell plasma. The latter author thought that he saw all kinds of bacteria grow up from the plasmatic granules within intact plant cells. but apparently no cultural experiments have been made, and it remains, therefore, doubtful, whether these bodies have been real bacteria or only cell inclusions of a similar shape, especially those called chondriosomes.

The numerous experiments made by *Fokker* (1887–1903) to support his "neue Bakterienlehre," which was, however, in fact the old heterogenetic hypothesis, are in so far of greater interest, as the author, late Professor of Hygiene at the University of Groningen, undoubtedly has been well acquainted with bacteriological methods of investigation, and he was able to report that he not only had under his microscope things looking like bacteria, but that he actually cultivated bacteria under conditions which would invalidate the easy explanation of "mere contamination." He confirmed the earlier observations of *Klebs* (1873), *Tiegel* (1874), *Zahn* (1884) and of others, that blood and parts of muscles aseptically won and kept, did not give bacterial growth, but that this became visible within parts of the liver, spleen, and kidneys. Blood alone or diluted with water remained equally sterile, but "hematocyts" appeared and developed to normal bacteria, when small amounts of blood were kept in nutrient solution (slightly acid broth of beef extract and lactose), either at 20°, or 37°, or at 50–52° C. The highest temperature proved to be most suitable. The appearance of these hematocyts, as shown in figure 203 on Plate XVI (reproduced from original fig. I, Pl. I) leaves hardly any doubt that they are regenerative bodies growing up from the gonidia contained within the pale blood corpuscles. That they are first Gram-negative, later gram-positive, that iodine gives them a brown stain, that they are resistant against alkali and acetic acid, and that they apparently multiply by budding, is also in full agreement with this assumption. Further experiments proved that bacteria developed from these round bodies (see fig. 204 on Plate XVI, reproduced from original fig. II on Pl. III); at room temperature a "comma bacillus," at 40° C. yellowish, gelatin liquefying bacteria, and at 52° C. another organism which showed budding and branching, probably an Actinomyces, were obtained. With the "comma bacillus" reproduction by small granules, produced inside of the parent cell, was also observed. *Fokker's* discovery that in cases of anthrax, especially during the first 12–17 hours, no bacilli are visible, but only granules, which stain like the nuclei of the spleen cells, and like the anthrax rods which develop from them, is of interest in this connection, though it does not, of course, support the Dutch author's assumption that it is the granules of the sick spleen cells which become anthrax bacilli. Some others of his findings, especially with regard to "heterogenesis" in milk, will be considered in Chapter III, as the development of regenerative bodies from the symplasm of milk bacteria has obviously caused this faulty hypothesis.

The cell granula theory of *Altmann* (1894) is similar to the earlier ones in so far as he, too, accepts cell granules and microörganisms as equivalent (p. 141), but his standpoint is different when he says (p. 146):

> Die Zellengranula lassen sich nicht züchten, sie sterben mit der Zelle ab.

On the other hand, *Hueppe* (1896, p. 31) was not quite right when he tried to discard all positive results by the following statement:

> Die Angaben über Bildung von Bakterien aus anderen Zellen und deren Bestandteilen durch Anamorphose des Protoplasma beruhen auf Verwechslungen von Zellkörnern in Milch, Blut, Geweben und von Fibrinausscheidungen und künstlich veränderten Kernbestandteilen mit Bakterien.

Münden (1896–1907) also secured some positive results concerning the development of bacteria from small granules present within plant or animal cells, but his fantastic "cytoblast" and "chtonoblast" hypotheses, founded upon this basis, are certainly of no value whatever. The same holds true concerning the theories promulgated by *J. H. Müller* (1898), who once more had to record negative results, when he tried to "develop" bacteria from living spores of fungi, while dying or dead material reacted differently.

That it is the gonidia of the bacteria which grow up within the cell, making use of the albuminous substances of the dead protoplasm, has been pointed out for the first time and with full certainty by *W. Winkler* (1899). Clean pieces of Hymenomycetes kept in steril wort gave him many "bacterioblasts," which developed new bacteria, just as had been described by *Karsten* thirty years earlier. That, as *P. Ernst* (1902) reported, bacteria often grow in a vertical position and in thick bunches on and around a mycelium, and that *Gaidukow* (1906) found his ultra-microörganisms frequently within closed cells of algae and fungi, is again in complete agreement with the earlier observations.

And it is now easily understood why in strictly pure, single-cell cultures of an alga *Dunbar* (1907) has seen development of different kinds of bacteria in a great number of cases, though extensive controls (over 4,000) proved that these could not be simply explained as contaminations by bacteria. It was again only the dead, not the living, alga cells which gave this growth. Whether the bacterial gonidia had been introduced with the alga, or whether they were, indeed, contaminations from the air, can not be decided. The special tests made with the isolated algae cells on gelatin and on agar are inconclusive, because under such conditions bacterial gonidia do not grow at all, or their growth remains so scant that only special attention in this direction will detect it.

M. E. Abbott's (1900) remark that the small coccoid bodies to be found in liver and other cells may belong to *B. coli* and other bacilli seems to be, indeed, the correct explanation of apparent heterogenesis found at such places; and it may also be considered to be beyond doubt that bacterial gonidia have played their part in the development of bacilli within animal cells, as observed by *Saski* (1907) and by *Portier* (1917).

The behavior of *Anaplasma marginale*, according to *Theiler's* (1910) report, a protozoon causing "gall sickness," seems to be, as far as can be surmised from his and *Sieber's* (1910) description, strikingly similar to that of *Fokker's* "hematocyts." The microscopic picture of these small chromatine granules, growing at the edge of the blood corpuscles and multiplying as such, is exactly like that furnished very frequently by bacterial gonidia. Comparatively large round bodies "studded with chromatine granules" were seen by *Ross* (1912) to occur in cases of spirochaetosis, and they are also by no means rare with *B. radicicola* and *Azotobacter*. Probably they will be found with all bacteria as soon as this subject will be studied more thoroughly.

When the gonidia live within the dead cell, making use of its protoplasm, they naturally become what *Prowazek* called Chlamydozoa, and if the alga used by *Dunbar* in his experiments was acid-fast, it is no wonder that all bacteria which developed in his cultures proved to be at first also acid-resistant.

It remains to be hoped that some staining reaction will be found later which would allow a differentiation between bacterial gonidia and cell granules, but in view of the ever-changing

composition of both kinds of these smallest units not very great expectations seem to be warranted. Therefore, the heterogenetic hypothesis can not be defeated definitely from this new point of vantage; that it has lost, however, practically all of its probability, is hardly to be disputed. Besides this, the results discussed above are of great practical interest, insofar as valuable suggestions offer themselves for a successful attack of the otherwise extremely difficult problem to secure a speedy upgrowth of normal bacterial cells from their gonidia, which on the commonly used substrates is often out of the question.

2. REPRODUCTIVE ORGANS IN THE DIFFERENT GROUPS OF BACTERIA.

The summary of what is known at present concerning the occurrence of the different types of reproductive organs among the various kinds of bacteria, which is to be given on the following pages for ready reference, will be arranged, on account of the reasons mentioned on p. 6, in the same manner as the review given in the second part of Chapter I along the old familiar lines of grouping. It is, of course, somewhat absurd to write, e. g., upon the spore formation of nonspore-forming bacteria, but we will have to tolerate temporarily such, it is to be hoped, not misleading "absurdities," because a new, more correct classification of the bacteria can not be attempted successfully, before many more results will have been gathered, than are available at the present time.

(a) COCCI.

The formation of minute and of comparatively large forms of micrococci, probably their gonidia and microcysts, were apparently first noticed by *Lübbert* (1886) in the course of his studies upon *Staphylococcus pyogenes aureus*. *Prove* (1887) recorded with his *Micrococcus ochroleucus* normal cells of 0.5–0.8μ, minute coccoid bodies of 0.1–0.3μ, and large forms of 1.6–1.8μ diameters; the latter were called "Dauersporen" on account of their considerable resistance against heat (30 minutes at 100° C.), but they have been evidently microcysts. *Prazmowski* (1888 *a*) found resistant forms regularly with *Micr. ureae*, which survived when exposed for 1 minute to 90° C., but were killed at 100° C. The whole cell was transformed, and no membrane was thrown off during germination. Nevertheless the author insisted that these were "endogenous" spores. Like this, so also the statement made by *DeToni* and *Trevisan* (1889, p. 1072) can not be accepted as referring to genuine endospores, although it reads: endosporae microsomae in coccis normalibus obvenientes.

Irregular rod-like regenerative bodies were observed by *Matzuschita* (1900) when he grew *Micr. flavus liquefaciens* and *M. rubefaciens* on salt agar (see figs. 5 and 6 on Plate I), while other micrococci, including *M. candicans*, did not react in the same manner. The last-named organism, however, gave analogous results when studied by *Löhnis* and *Smith* (1916 *a* and *b*); besides the formation of regenerative bodies the production of gonidia and of microcysts has been discussed in these papers. Some photographs were reproduced as figures 2–4 and 8 on Plate I and 168–169 on Plate XII. The "protospores" found by *Fedorowitsch* (1902) with micrococci as with other bacteria leave no doubt about their being gonidia. Such "exogenous globules" were also seen by *Almquist* (1917) with *Micr. pyogenes*, while his "macrococci" of *Micr. Thulini* furnish another example of microcyst formation.

The important rôle played by the gonidia in the life cycle of the Gonococcus was discovered by *Wertheim* (1899) and more thoroughly studied by *Herzog* (1910–1913), who also secured analogous results with Meningococcus. The latter have been confirmed and considerably extended by *Hort* and his collaborators (1915–1917), whose observations relating to the development of gonidangia, which were mistaken for "asci," are of special importance.

Some data concerning the formation of gonidia, regenerative bodies, and of microcysts by *Sarcina flava* and *Planosarcina ureae* have been secured by *Löhnis* and *Smith* (1916 *a* and *b*). The production of regular endospores by the last-named organism, first described by *Beijerinck* (1901 *a*), together with other morphological data exhibited in the course of its life cycle, points to certain relations with spore-forming bacilli, a fact which was already indicated in an earlier note by *Olsen* (1897).

That the "Dauersporen" seen by *Salomonsen* (1876) in blood cultures of streptococci, have been microcysts, is hardly to be doubted, and this is beyond question in regard to the "spores" or "kystes" of *Leuconostoc mesenterioides*, according to the description given by *Van Tieghem* (1879 *c* and 1884, p. 1108). The same holds true concerning the "arthrosporae macrosomae in filamentis huc illuc sparsae," which were mentioned by *De Toni* and *Trevisan* (1889, p. 1054) as characteristic of the genus Streptococcus. The drawings of streptococci made by *Babes* (1895), which were reproduced as figure 3 on Plate B, those of *Leuconostoc hominis* of *Hlava* (1902), reproduced as figure 4 on Plate B, as well as that of *Streptococcus pyogenes*, made by *Hewlett* (1902) and reproduced as figure 72 on Plate P, are of great interest on account of the details contained therein in regard to gonidia, gonidangia, regenerative bodies, and microcyst formation. All these various types of reproductive organs were also found by *Thiercelin* (1899–1903), when he studied his Enterococcus. His observations upon its gonidia ("microblastes") and gonidangia deserve our special attention, and have been quoted, therefore, more fully on pages 104 and 126. Formation and behavior of these "microblasts" have been thoroughly investigated by *Thiercelin* and *Jouhaud* (1903 *a* and *b*). The peculiar splitting up of microcysts into 3 or 4 parts was first described by *Babes* (1908), and some data upon their resistance against heating (live steam for more than 20 minutes) were obtained by *Holman* (1914). The avirulent, resistant, Micrococcus-like subculture, grown by *Eyre* and *Washburn* (1897) from typical pneumococci, has been evidently a pure culture of regenerative bodies, such as have been photographed by *Axelrad* (1903) from a contact preparate of *Streptococcus lanceolatus*, reproduced as figure 146 on Plate XI.

The important rôle played by filterable gonidia of streptococci as filterable virus in diseases like poliomyelitis, was discussed on the foregoing pages (pp. 145–146).

A good description of gonidangia produced by *Streptococcus lactis* has been furnished by *Maddox* (1885). The spore-like terminal bodies seen by *Weigmann* (1899) at rod-like forms of this species, are probably to be classed as regenerative bodies. Our own experiments with lactic acid streptococci proved once more the regular occurrence of gonidia, regenerative bodies and microcysts. Photographs have been reproduced as figures 11 on Plate I and 170 on Plate XII.

(*b*) NONSPORE-FORMING RODS.

The report and pictures given by *Hauser* (1885) in his Proteus monograph, of what he calls the involution forms of this organism, are mostly to be interpreted as relating to the formation of gonidangia and to the occasional transformation of their content into one rudimentary endospore. A characteristic photograph has been reproduced as figure 120 on Plate X. *Bac. piscicidus agilis* was found by *N. Sieber* (1895) to produce genuine endospores, though it exhibited in all other respects the character of the Proteus group. With *B. Zopfii*, whose arthrospore formation has been studied by *Kurth* (1883), analogous results concerning typical endospore formation were recorded by *Swellengrebel* (1904).

The large globules produced by *B. bifidus* are to be interpreted, according to the description given by *Tissier* (1900), as either gonidangia or regenerative bodies. It was stated in that paper (p. 90):

> De ces boules partent en rayonnant des corps bacillaires d'une grande finesse qui se subdivisent.

The fairly high resistance (80° C. for 1 hour) shown by the Boas-Oppler bacillus, when tested by *C. Sternberg* (1898), which was believed by this author to be due to the presence of spores, may just as well have been the result of the formation of regenerative bodies. The observations of *Sandberg* (1904) and of *Rodella* (1908) are in accordance with this assumption. Some data furnished by the last-named author indicate that also the liberation of gonidia was noticed by him in some cases. *Fokker* (1901), however, seems to have had, indeed, some really endospore-forming lactobacilli. As far as can be seen from his report, his results agree closely with those secured by *Noguchi* (1910), who succeeded for the first time to change experimentally the anaerobic *Bac. bifidus* into an aerobic spore-forming bacillus, resembling *B. mesentericus fuscus*.

The very conspicuous regenerative bodies of lactobacilli have been mentioned by *Weigmann*, *Gruber*, and *Huss* (1907), *Kuntze* (1908), *White* and *Avery* (1909), *Rubinsky* (1910), *Löhnis* and *Smith* (1916 *a* and *b*), and by others. Figures 148 on Plate XI and 172 on Plate XII demonstrate their characteristic appearance; in the center of the last-named picture a germinating regenerative body is visible. Part or all of what has been described as "granule" formation by *Luerssen* and *Kühn* (1908), *White* and *Avery* (1909) and by *Koegel* (1914), is undoubtedly to be explained as relating to the production of gonidia. As this is quite general, but at the same time naturally varying to some extent, presence or absence of the "granules" can not be made the basis for separating several types or species of lactobacilli, as was done by the first-named authors. *Kuntze's* experiments have already demonstrated the instability of this feature.

The picture of a pure culture of regenerative bodies of *B. cholerae gallinarum*, which was made by *Itzerott* and *Niemann* (1895), who were obviously not aware of the special character of these dark round cells, was reproduced as figure 30 on Plate III. The gonidia of this species, as well as of *B. septicaemiae murium*, have been studied by *Fedorowitsch* (1902) under the name of protospores.

Gonidia, gonidangia, regenerative bodies, and perhaps microcysts, too, may have been seen by *Albrecht* and *Ghon* (1900), when they made the drawings of *B. pestis*, which have been reproduced as figure 11 on Plate D. The important rôle played by the gonidia in the reproduction of this species was pointed out by *N. K. Schultz* (1901). Analogous results with *B. pseudo-tuberculosis rodentium* have been recorded by *Zlatogoroff* (1904). *Maassen* (1904) made an interesting photograph of what he calls teratologic growth of *B. pestis*, reproduced as figure 118 on Plate X as a very suggestive object for comparison with *Hauser's* Proteus picture (fig. 120).

The formation of the typical round lateral regenerative bodies of *B. pneumoniae* has been shown in figure 171 on Plate XII, which was reproduced from our second preliminary paper (*Löhnis* and *Smith* 1916 *b*). Gonidia, regenerative bodies and gonidangia of another member of the *B. pneumoniae* group, the so-called *Proteus hominis capsulatus*, have been fairly well studied by *Bordoni-Uffreduzzi* (1888 *b*). Two interesting drawings of his have been given as figure 14 on Plate D and figure 123 on Plate X; the latter, made from a liver cut, is especially instructive. The production of terminal exospores by *B. acidi lactici* has been ascertained by *Hueppe* (1884) in his first investigations upon the microbial alterations of the milk by microscopic tests as well as by boiling. Though some years later, with *Hueppe's* consent, *Epstein* (1900) has revoked these findings, it still remains probable that they have been correct (cf. p. 137). The photograph of *B. aerogenes* made by *Maassen* (1904), reproduced as figure 119 on Plate X, equally indicates the possibility of inducing this like other "nonspore-forming" bacilli to produce exo- and endospores. *Kitt's* drawing of *B. phlegmasiae uberis*, a variety of *B. aerogenes*, is another good example of the mode of producing regenerative bodies within this group. (See fig. 145 on Plate XI.) That an old stock culture of *Actinobacter polymorphus Duclaux* presented itself to *Lehmann* and *Neumann* (1912, p. 206) as closely resembling *Sarcina tetragena*, would also have to be explained as another case of a pure growth of round regenerative bodies, provided that no error in making the transfers has occasionally happened (cf. also p. 49).

The participation of gonidia and regenerative bodies in the life cycle of *B. coli* has been studied by *Almquist* (1893), *Adami*, *Abbott* and *Nicholson* (1899) *M. E. Abbott* (1900), *Fedorowitsch* (1902), *Ohlmacher* (1902), and more recently by *Kellerman* and *Scales* (1916), whose very interesting photographs have been reproduced as figures 182, 185, 199, and 200 on Plate XV. The drawing made by *Hort* (1917 *a*) of all forms which he saw in his Coli cultures, reproduced as figure 180 on Plate XIII, deserves also to be examined carefully. Terminal sporeformation of the type seen by *Hueppe* with his *B. acidi lactici*, has been recorded for *B. coli*, though only in one case, by *Piccoli* (1896). The very close similarity of *Maassen's* (1899) *B. esterificans*, which, however, despite its otherwise coli-like character, showed a more pronounced tendency to develop such polar spores, is noteworthy in this connection. What

Rogers, Clark, and *Davis* (1914), as well as *Burton* and *Rettger* (1917), have classified as sporogenous members of the Colon-Aerogenes group may have been analogous strains; but it must be left in doubt whether the definition of this group almost entirely by biochemical features, as given by these authors, has not led to an essential alteration in the meaning of the name of the group. The picture made by *Matzuschita* (1900) of large "involution" forms of *B. coli*, reproduced as figure 36 on Plate III, apparently demonstrates a type of gonidangia formation. Another strain was reported to have furnished large globules. Transformation of the inflated parts of threads into large round bodies was actually observed by *Wilson* (1907).

The "small sporoid bodies" found by *Eberth* (1880) in *B. typhi*, 1 to 3 to the rod, have been undoubtedly gonidia; while the round terminal unstainable bodies, described by *Gaffky* (1884) as the spores of this species, seem to belong into the same class as the similar formations found in a few cases with *B. coli* and *B. acidi lactici*. Unstainable spaces within the rods, which have been considered for sometime by *Klebs* (1887, p. 174) and others to be spores, are to be explained with great probability as vacuoles. The negative findings of *Buchner* (1888) and of *Pfuhl* (1888) in regard to typhoid "spores" confirm this view, but, despite a widespread opinion, they can not be accepted as full proof that the terminal bodies seen by *Gaffky* were not spores. This point remains to be settled by future investigations. *Almquist's* (1893–1917) studies, which were mostly centered on this species, have brought out many interesting details concerning formation and further development of gonidia and regenerative bodies by *B. typhosus*. Some of his photographs were reproduced as figures 135, 136, and 138 on Plate XI. Large globular gonidangia, which are mentioned in one of his latest papers (1916), have been described before by *Gamaleia* (1900). Direct microscopical investigations upon the reproduction of normal rods from so-called protospores, i. e., from gonidia, have been made by *Fedorowitsch* (1902). The drawings published by *Hort* (1917 *a*) and reproduced as figure 179 on Plate XIII, furnish a comprehensive picture of probably all forms which may occur in the course of the development of the gonidia and regenerative bodies of the typhoid organism.

Analogous results as with *B. typhosus* have been recorded by *Almquist* (1908–1917), as well as by *Hort* (1917*a*), in regard to paratyphoid and dysentery bacilli, and by *Meirowsky* (1914 *b*) with *B. paratyphosus B.* and *B. enteritidis*. *Meirowsky's* drawings of the paratyphoid organism, reproduced as figure 178 on Plate XIII, make an excellent counterpart to *Hort's* composite pictures of *B. coli* and *B. typhosus*.

Radiate growth, shown in *Hort's* pictures as result of the upgrowth from the gonidial stage, has been found by *Beijerinck* and *van Delden* (1902) to be especially frequent with *B. radiobacter*, which like *B. radicicola* is closely related to the Colon-Aerogenes (*B. pneumoniae*) group. Our own experiments have furnished many confirmative results (*Löhnis* 1905 *a*, *L.* and *Smith*, 1916, *a* and *b*). However, not all radiate growth of bacteria is of the same origin. Sometimes a similar development starts from the symplastic stage, in other cases a stellate arrangement of adult cells is noticeable at the time of conjunction (see Chaps. III and IV). The small "swarming bodies" (gonidia) of *B. radicicola* are known as long as the species itself (*Beijerinck*, 1888). *Frank* (1890), *Prazmowski* (1890), *Morck* (1891), and *Atkinson* (1893) soon confirmed and extended the findings of the Dutch bacteriologist. Some characteristic drawings made by *Morck* were reproduced as figures 66 and 67 on Plate P; they illustrate clearly the formation of the gonidia in the rods, as well as in the gonidangia. The following description given by *Greig-Smith* (1900) concerning the liberation of a budding gonidium of *B. radicicola*, pictures in an excellent manner how this occurrence looks under the microscope not only in this case, but always when motile gonidia are making their way to liberty:

> When the bud has separated from the parent protoplasm it pulls and tugs in its endeavor to free itself from the capsule membrane containing the motionless mother cell, and we have an appearance exactly like that of an ant attempting to drag along a twig which proves too heavy for its powers.

"Zoospores" (gonidia) growing up to new rods within a "mother spore" (gonidangium) have been seen by *Hartleb* (1900). What *Hiltner* (1900) called spores may have been gonidia as well as regenerative bodies, and the so-called sporangia of *B. radicicola* (*Hiltner* and *Störmer*, 1903, pp. 210, 262) are to be interpreted either as gonidangia or as large irregular regenerative

bodies, produced by the symplasm, a type of the so-called bacteroids, which readily break up into round regenerative bodies. Photographs were reproduced as figures 195 and 196 on Plate XV, and more data relating to this type of regenerative bodies are to be found in the papers of *Rossi* (1907), *Peklo* (1910), and *Spratt* (1912). An exceptionally high resistance of such bodies against heating has been reported by the last-named author.

The big inflations of acetic acid bacteria, which were studied by *E. Chr. Hansen* (1879, 1894, see fig. 15 on Plate E), are typical gonidangia. Gonidia and microcysts have been also seen by the Danish author, and excellent drawings of regenerative bodies, published by *Henneberg* (1898) were reproduced as figure 57 on Plate N.

Some white and yellow short rods, found by *A. Wolff* (1908) in milk, furnish another interesting example of a comparatively high resistance of regenerative bodies against heating. At least part of the round forms withstood boiling for 15 minutes. Large pear- or bottle-shaped cells, probably gonidangia, were also observed in the cultures.

That the yellow or red pigmented spore-forming bacillus isolated by *Morgenthaler* (1916) is to be considered to represent probably a sporogenous variety of *Bact. herbicola*, and that *B. violarius acetonicus* of *Bréaudat* (1906) appears to be the analogous counterpart to *Bact. violaceum*, has been pointed out on page 137.

Gonidia, gonidangia, and regenerative bodies of *B. cyanogenes* have been correctly described by *Neelsen* in 1880. But what he called the spores of this species have been evidently mostly, if not all, vacuoles. Genuine exospores, however, have been found by *Hueppe* (1884).

The very interesting fact that gonidia and regenerative bodies of *B. fluorescens* have been photographed by *R. Koch* as early as in 1877, though later overlooked entirely, has been mentioned on page 92. Only one year later *Ewart* (1878 *a*) published another but more complete description of the same occurrence. One of our own photographs (*Löhnis* and *Smith*, 1916 *a*, fig. 40) has been reproduced as figure 110 on Plate X as counterpart to the picture made by *R. Koch* 40 years earlier, reproduced as figure 109. Another characteristic illustration of the next step in the development of what *Koch* called lateral spores was shown as figure 174 on Plate XII (*Löhnis* and *Smith*, 1916 *b*, fig. 28). Genuine spore formation by some Fluorescens strains has been recorded by *Tanner* (1918). *Bact. bruneum*, of which *Matzuschita* (1900) obtained a pure culture of globular regenerative bodies (see fig. 18 on Pl. II) may be also mentioned here, because it is hardly to be doubted, that it is to be classed as one of the brown varieties which are rather common in the Fluorescens group. Special studies upon gonidia, gonidangia, and regenerative bodies of *B. fluorescens* and of another organism with polar flagella (*Pseudomomas cerevisiae*) have been made by *Fuhrmann* (1906–1908).

That Nitrosomonas as well as Nitrobacter are endowed with the same types of reproductive organs is fairly well indicated by the photographs made by *Winogradsky* (1891–1892), reproduced as figures 49–53 on Plate V. And it is very probable, as was pointed out on page 135, that *Winogradsky's* Nitrosococcus is no separate species, but a pure culture of regenerative bodies of Nitrosomonas.

(c) SPORE-FORMING RODS.

That *B. anthracis* is accompanied within the tissue by its gonidia and regenerative bodies has been demonstrated by *R. Koch* (1877) in the first photograph which he made of this organism (reproduced as fig. 111 on Pl. X); though no explanation was given by him in regard to the round bodies visible therein. It was left, therefore, to *Ewart* (1878 *b*) to give the first detailed description of the mode of formation and development of these reproductive organs. Although he speaks of spores, it is quite evident from his general report, as well as from the fact that these bodies did not withstand boiling, that the term was used in a different manner as is customary to-day. Soon afterwards *Fokker* (1881) strongly emphasized the important rôle played by these coccoid reproductive organs, especially in the beginning of the disease, which had been overlooked by *R. Koch*, though they were once more photographed by him (*Koch*, 1881) in the picture reproduced as figure 113 on Plate X. *Archangelski* (1883), *Roloff* (1883), and *E. Klein* (1883) soon furnished more confirmative material in this direction; pure cultures of the round bodies were grown by the first-named author through three successive transfers

and then reverted promptly to normal rods. Equally early discoveries made by *Toussaint* upon the formation of gonidangia by *B. anthracis*, and upon the liberation and further development of the gonidia produced therein, have been reported in the textbook of *Magnin* and *Sternberg* (1884, p. 150). Similar findings were made by *Weibel* (1888) and by *Schroen* (1890). The possibility of an occasional replacing of the regular endospores by gonidangia has become very clear by these contributions. A curious, but highly characteristic statement, by which *Fraenkel* (1891) tried to discard gonidia and regenerative bodies of *B. anthracis* as "unnecessary" and "illegitimate," because they "merely" reproduce the "legitimate" rods, has been quoted on page 27. *Rodet* (1894, p. 18) confirmed once more the correctness of *Toussaint's* observations and the results obtained by *Chauveau* and *Phisalix* (1895) with an Anthrax strain of low virulence, in which the endospore formation was entirely and constantly replaced by the production of round terminal regenerative bodies, represents another important contribution to our knowledge of the physiological value of these reproductive organs. The photograph made by *Matzuschita* (1900) of *B. anthracis* grown on salt agar, reproduced as figure 57 on Plate V, shows also regenerative bodies mixed with endospores. And the photograph published by *Günther* (1906), which was reproduced as figure 112 on Plate X, makes a very interesting counterpart to the two Anthrax pictures of *R. Koch* (figs. 111 and 113). *Růžička* (1908) came again very close to the results secured by *Ewart*, *Toussaint*, and others of the earlier workers, whose publications evidently had remained unknown to him. *M. Müller* (1912) thinks that asporogenous strains of *B. anthracis* occur much more frequently in nature than is generally assumed; and *McFarland* (1916, p. 359) gives in his textbook an interesting picture of "Anthrax bacilli in glomeruli of kidney" showing many small round bodies close to and stained like the bacilli, which is very similar to *Koch's* early photographs. *Henri's* important paper (1914) upon the transformation of regular Anthrax bacilli into round (regenerative) bodies and into an asporogenous Actinomyces-like growth has been quoted repeatedly. The most characteristic photographs contained therein were reproduced as figures 58–63 on Plates V and VI.

A good picture of a lateral regenerative body of *B. subtilis* has been published without comment by *Hiss* and *Zinsser* (1914); it was reproduced as figure 150 on Plate XI. Other photographs showing gonidia and regenerative bodies as formed by this organism have been furnished in our preliminary papers (*Löhnis* and *Smith*, 1916 *a* and *b*); two of them were reproduced as figures 65 on Plate VI and 197 on Plate XV.

The big globules found by *Blau* (1905, p. 125) in cultures of his *B. cylindricus*, which either contained several small plasmatic globules or one endospore, evidently have been gonidangia, while other round cells, seen by *A. Meyer* (1901) in cultures of *B. cohaerens*, *Ellenbachensis* and *ruminatus*, have been typical microcysts. Two drawings made by the last-named author have been reproduced as figure 64 on Plate O.

A spore-forming aroma producing bacillus, isolated by *Burri* (1897) from Swiss cheese, exhibited quite constantly with all six strains studied "granular differentiation" of the plasma, coiling of the granular rods into ring forms and development of large globules of several micra diameter, which appeared like a conglomerate of small cocci. In the textbook of *Lehmann* and *Neumann* (1912, p 460), wherein the bacillus was named *B. bernensis*, no indication whatever is given concerning this interesting report of the Swiss author in regard to the formation of gonidia and gonidangia by this species.

The large globular forms of *B. Megaterium*, described by *DeBary* (1884, p. 503), may have been either gonidangia or microcysts, while the "Bacillen-Säckchen," found by *Schroen* (1890) with this species, as well as with *B. anthracis*, leave no doubt as to their having been gonidangia. The same holds true with regard to similar cells of *B. Ellenbachensis* observed by *Stoklasa* (1898, p. 120).

Regular endospore formation was recorded by *Zopf* (1883) with the rod-like, but also with the large globular cells of *B. tumescens*.

Bac. oxalaticus was found by *Kuntze* (1904) to produce abundantly "swarming bodies" (gonidia). Their liberation was seen, but not their further development.

That the large round cells of Azotobacter are a type of growth of endospore-forming bacilli became evident from the behavior of some of our old stock cultures (*Löhnis* and *Hanzawa*, 1914). Investigations made by *Ford* (1916) upon numerous sporogenous bacilli have shown, on the other hand, that many, if not all of them, are able to produce cells looking very much like Azotobacter. What *Beijerinck* (1901) called involution forms of this species have been probably gonidangia, as was pointed out on page 126 when discussing *Beijerinck's* photograph of these cells, reproduced as figure 189 on Plate XV. The very characteristic microcysts of *B. Azotobacter* have been described as "spores" by *H. Fischer* (1905), *Krzemieniewski* (1908), and *Prazmowski* (1912). The last-named author's extended investigations upon this species have added much valuable material to our knowledge of the production and development of the gonidia and gonidangia of Azotobacter. Some of our own photographs of the different types of reproductive organs, as found with this organism, have been reproduced as figures 19–21 on Plate II, 68–70 on Plate VI, 186–188, 190, 191, and 193 on Plate XV.

Good development of lateral regenerative bodies was shown by a bacillus isolated from "Hackfleisch" (chopped meat), when it was grown by *Maassen* (1904) on lithium chloride agar; a photograph of it was reproduced as figure 149 on Plate XI. A not yet completely studied yellow bacillus, No. 41 of our collection, apparently related to *Maassen's* organism, exhibits very prominently the formation and development of gonidia and regenerative bodies, as is illustrated by the photograph reproduced as figure 183 on Plate XV.

An interesting description of the upgrowth of *B. Amylobacter* from what seems to have been its gonidial stage has been given more than 50 years ago by *Trécul* (1867 *b*). *Winogradsky* (1902), on the other hand, noticed the production of small coccoid bodies by his *Clostridium Pastorianum*, but he was of the opinion that they were unable to act as reproductive organs. Asporogenous strains, developed from this species, were morphologically, as well as physiologically, so different from the original culture, that they were hardly recognizable as such.

The "cocco-gonidia" of *B. Chauvoei* have been studied by *Ehlers* in 1884. In the animal they grew up to typical rods. The photographs published by *Grassberger* (1903), *Grassberger* and *Schattenfroh* (1907), and by *Hibler* (1908), some of which were reproduced as figures 74–77 on Plate VII, 115 and 116 on Plate X, and 151 on Plate XI, contain many interesting details concerning gonidia, gonidangia, and regenerative bodies, though they have been grossly misunderstood, especially by the last-named author, as was discussed on pages 67 and 95.

That according to *Hibler's* observations old weakened cultures of *B. Chauvoei* are inclined to produce polar spores, is of special interest when brought into parallel with the so-called involution forms of this species, as photographed by *Fraenkel* and *Pfeiffer* (1895, reproduced as fig. 117 on Plate X) and also with the fact found out by *Grassberger* and *Schattenfroh* (1907), that temporarily asporogenous anaerobic butyric acid bacilli, when returning to spore formation, at first pass through a stage where they exhibit the appearance of a typical plectridium.

(*d*) SPIRILLA AND SPIROCHAETS.

The various reproductive organs of *V. cholerae* (gonidia, gonidangia, and regenerative bodies) have been seen apparently for the first time by *Ferrán* (1885), but the various unfounded hypotheses which he liberally added to his observations, have been evidently the cause that the latter did not meet with adequate interest, though they were confirmed, at least in part, by *Ermengem* (1885, pp. 334–342). The results secured by *Dowdeswell* (1889–1890) and by *Schroen* (1890) are in complete agreement with those of *Ferrán*, but they, too, despite their being all based on direct continuous microscopic examinations, have not been acknowledged by the then dominating German bacteriologists. Even the careful and undoubtedly very correct studies of *Hueppe* (1885) upon the formation and germination of the terminal round regenerative bodies (or exospores?), which he called arthrospores, were not "officially" accepted Because *Kitasato* (1889) was not able to observe germination of the granules resulting from the "granular decomposition" of the cholera bacilli in old cultures, *Hueppe's* quite different positive findings were declared by *Woodhead* (1891, p. 168) and by *Pfeiffer* (1896, p. 536) to be entirely erroneous, though also *Babes* (1889) reported to have obtained the same results as *Hueppe*.

A good photograph of cholera regenerative bodies, reproduced as figure 140 on Plate XI, has been published by *Friedrich* (1892); but no word of explanation was given by him in regard to the round bodies clearly visible in the picture. Upgrowth of new vibrios from the gonidia has been recorded by *Cantacuzène* (1898), *Bliesener* (1901), *Kohlbrugge* (1901), and *Fedorowitsch* (1902), while the germinating globules seen by *Nakanishi* (1901) have been apparently regenerative bodies. The large globules visible in the photograph made by *Maassen* (1904), which was reproduced as figure 121 on Plate X, are gonidangia wherein spore-like bodies have replaced the normal gonidia. Thorough studies upon formation, multiplication, and germination of the round regenerative bodies of *V. cholerae* have been contributed by *Almquist* (1904–1917); they confirm once more the accuracy of *Hueppe's* early work, and the photograph reproduced as figure 139 on Plate XI deserves to be studied jointly with figure 49 on Plate M. A photograph of a pure growth of the round reproductive organs of the cholera organism made by *Hammerl* (1906) has been reproduced as figure 158 on Plate XII. Many data given in the more recent publications of *Bittrolff* (1912) and of *Stamm* (1914) are in full agreement with the early findings of *Ferrán, Dowdeswell,* and *Schroen.*

Very similar results have been recorded by *Finkler* and *Prior* (1884–1885) with the vibrio isolated by them from cases of cholera nostras. The formation of gonidia, gonidangia, and of regenerative bodies has been fairly well studied. Germination of the round regenerative bodies of this species, as well as of *V. Metchnikovii,* was also observed by *Nakanishi* (1901). That the spores attributed by *Gamaleia* (1888) to the last-named organism have been such indeed may be justly doubted; the staining reaction, upon which this opinion was based, is certainly not so conclusive as was generally assumed at that time. Evidently the same holds true in regard to the "spores" or "sporelike bodies" found by *Van Tieghem* (1879 *b*), *Weibel* (1888), *Hueppe* (1891), and others with various vibrios. They all have been mistaken gonidia, regenerative bodies or vacuoles. With a *Vibrio proteus,* isolated by *Kohlbrugge* (1900) from water, the reproduction of normal cells by gonidia and regenerative bodies has also been ascertained.

Germination of the so-called spores of *Spirillum amyliferum* has been recorded by *Van Tieghem* (1879 *a*). How the sprouting of the gonidia may lead to a characteristic branching of the parent cells has been shown by *Sorokin* (1887–1890). Some drawings of his *Spirillum endoparagogicum* were reproduced as figure 29 on Plate H. That the term "spores" was incorrectly applied in this case by the author is proven by his statements that these "spores" had no distinct membrane and were not more resistant against heating than the vegetative cells. The analogous round bodies found by *Esmarch* (1887) within *Spirillum rubrum* leave also hardly any doubt that they are to be classed as gonidia. As *Meirowsky* (1914 *b*) has demonstrated, they may grow up in exactly the same manner as those of *Sorokin's* spirillum. A sketch illustrating this fact was reproduced as figure 30 on Plate H; Plate XIV offers further information. Interesting data upon the regenerative bodies of this species, as well as of *Spirillum tyrogenum,* have been also collected by *Meirowsky.* Figure 167 on Plate XII and the lower part of Plate XIV may be compared in this respect. Branched forms like those described by *Sorokin* and *Meirowsky* have been seen by *Kutscher* (1895) with *Spirillum Undula* and *Sp. Serpens.* But neither he nor *Zettnow* (1896) reached a correct insight into the real character of the round bodies within the spiral cells, which are the cause of this branching. Photographs made by *Doerr* (1905) of *Spirillum pyogenes* show some other case of branching and budding; they, too, were published, however, without any explanatory remark in the text. Two salt-water spirilla furnished us (*Löhnis* and *Smith* 1916 *a*) very good examples of the mode of branching first seen by *Sorokin.* Formation and germination of the round terminal regenerative bodies were equally conspicuous.

The ability of certain spirochaets to produce arthrospores has been discovered by *Van Tieghem* (1879 *b*) in regard to an oyster parasite, and by *Zopf* (1881) with *Spirochaeta plicatilis.* Their findings have been recently confirmed by *Gross* (1912–1913), whose drawings were reproduced as figure 63 on Plate O, and by *W. H. Hoffmann* (1912).

The first information upon the occurrence of motile gonidia with *Spirochaeta Obermeieri* and their participation in the life history of this species has been furnished by *Heydenreich,*

Guttmann (1880), and *Albrecht* (1881). In regard to *Spirochaeta pallida* analogous results have been secured by *Wechselmann* and *Löwenthal* (1905), *Leuriaux* and *Geets* (1906), *McDonagh* (1912–1913), and *Meirowsky* (1914). Data concerning the round terminal and lateral regenerative bodies of this species were also published by the last-named author, as well as by *Mühlens* (1907), by *Krzysztalowicz* and *Siedliecki* (1908), and by *Selenew* (1910). Similar facts have been recorded with various other spirochaets by *Krienitz* (1906), *Mühlens* and *Hartmann* (1906), *Gonder* (1909), and especially by *Noguchi* (1911–1912) with all his pure cultures of different spirochaets (*Sp. pallida, micro-* and *macrodentium, mucosa, Duttoni, phagedenis* and *gallinarum*). Gonidia, as well as regenerative bodies, were also observed by *Calmette* (1893) with the spirochaetelike organism, discovered by him in cases of typhus exanthematicus, by *Bonhoff* (1905) with his *Spirochaeta vaccinae*, by *Breinl* (1905) and *Leishman* (1918) with *Spirochaeta Duttoni*, by *Fantham* (1911) with different species, *by Hindle* (1911) with *Spirochaeta gallinarum*, by *Bosanquet* (1911) with *Spirochaeta anodontae*, by *Tunnicliff* (1913) with a spirochaete associated with infections of the accessory sinuses, and by *Inada* and his collaborators (1916) with *Spirochaeta icterohaemorrhagica*. The rôle played by the "infective granules," and their ability to reproduce the spirochaets has been further discussed by *Leishman* (1909–1918), *Balfour* (1911–1913), *Rüther* (1910), and by *King, Baeslack* and *Hoffmann* (1913).

The formation of microcysts by spirochaets has been studied by *Breinl* (1907), *Dutton* and *Todd* (1907), *Doflein* (1909), *Gonder* (1909), *Fantham* (1911), and by *Inada* et al. (1916). As the first-named authors found out, the gonida are liberated within the microcyst, which, therefore, acquires the character of a gonidangium.

The motile gonidia of fusiform bacilli have been discovered by *Plaut* (1907) and their regenerative bodies by *Ellermann* (1907) who, however, thought they were to be classed as involution forms. *Rosenow* and *Tunnicliff* (1912) observed the slipping out of the gonidia from the bacilli, whose ends may become inflated, assuming the character of gonidangia. Multiplication of the "cocci" as such was also seen.

(e) MYCO- AND TRICHOBACTERIA.

With *B. tuberculosis* gonidia, gonidangia, and regenerative bodies have been seen undoubtedly, whereas concerning arthrospores and microcysts no such definite statement can be made, though it is probable that they, too, have been observed. The 2–6 unstainable "spores," attributed by *R. Koch* (1882–1884) to his bacillus, have been either vacuoles or gonidia. Motile gonidia ("Schwärmsporen") were discovered by *Klebs* (1883 *a*). Similar "grains bien colorés" have been mentioned by *Babes* (1883), but in addition swellings of the bacilli "suivant leur longeur" were registered, which may have been growing gonidangia. The occurrence of these reproductive organs with tubercle bacilli has been ascertained by *Schroen* (1886–1904). The description given by *Lutz* (1886) of the coccoid bodies within the bacilli, and of the large round deeply staining or not stainable thick-walled bodies at the end of the rods, leaves no doubt upon their being gonidia and regenerative bodies or exospores, respectively. *Metchnikoff* (1888 *a*) observed that oval cells broke off from short side branches, but whether these should be classified as arthrospores or as regenerative bodies, can not be decided at present. His drawings, reproduced as figure 38 on Plate J, do not permit a final conclusion. Some of the large swellings shown look very much like gonidangia. Slipping out of the gonidia was seen by *Mafucci* (1892). The occurrence of unstainable sporoid bodies within terminal swellings of the bacilli has been recorded by *F. Fischel* (1893), while *Sander* (1893, p. 277) studied not only the formation but also the germination of deeply staining, polar regenerative bodies. The exceptionally high resistance, ascribed by *Marpmann* (1893) to "spores" of the tubercle bacilli, which are reported to have not died when kept for 1 hour in the steam, can not be fully explained at present. If not the result of a faulty test, which seems most probable, it may be that either sporelike bodies, such as those seen by *Lutz* and by *Fischel*, have reached an exceptionally high degree of resistance, or comparatively large clumps of symplasm have been present, which have shielded some of the germs enclosed therein. Simultaneous upgrowth of numerous thin threads from clubs (i. e. gonidangia) of the tubercle bacilli has been noticed by *Coppen-*

Jones (1893). *Semmer* (1895) reported that he saw the small globoid bodies reproduce normal bacilli, after they had been liberated by rods and clubs.

A characteristic sketch of regenerative bodies made by *Crookshank* (1896) has been reproduced as figure 55 on Plate N. *Schürmayer* (1898 *a*) met with small motile not acid-fast granules, which either multiplied as such or grew again up to rods. The pictures published by *Arrigo* (1900), which were reproduced as figures 103 and 104 on Plate IX, are very suggestive of arthrospores and microcysts; but as the mode of formation of these bodies is not definitely known, the possibility remains that they, too, have been gonidia and regenerative bodies. Arthrospores ("conidia") produced by "aerial hyphae" of the tubercle organism, were also recorded by *Droba* (1901), besides lateral regenerative bodies, which he called "zygo- and stylospores." Other instances of germinating tubercle gonidia have been mentioned by *Fedorowitsch* (1902) and by *Rosenblat* (1905). In the latter case arthrospores, too, may have been seen; and the so-called "Splitter" of the tubercle bacilli, as found by *Spengler* (1905–1907), apparently have also included both types of reproductive organs. The description which *Betegh* (1908) furnished of them confirms this view. That the "granules" of *Much* (1907) are to be interpreted as gonidia is beyond doubt, and it is equally certain that much of what has been written about this discovery by *Much* (1907–1909), *Wirths* (1908), *Knoll* (1910), *Heinrich* (1912) *Kirchenstein* (1912–1913) and by others, could have well been spared if the earlier observations would have been properly considered. An interesting, but not easily accessible, contribution relating to the tubercle gonidia, whose partial filterability was ascertained in this case, was published by *Fontes* (1910). That the acid-fast as well as the not acid-fast "cocci" produced by the tubercle bacilli may develop as such has been further studied by *Maher* (1910–1913). The large acid-fast coccoid bodies seen by *Wherry* (1913) have been evidently regenerative bodies. Probably the most thorough investigation upon formation and development of gonidia and regenerative bodies of *B. tuberculosis* thus far published has been made by *Meirowsky* (*1914 b*); some of his pictures were reproduced as figures 162–164 on Plate XII and on Plate XIV.

That *B. leprae* is able to develop regenerative bodies has been ascertained by *A. Neisser* (1881) and by *G. A. Hansen* (1882), both of whom called them spores. Gonidia, as well as regenerative bodies and exospores, of this organism have been studied by *Babes* (1883) and more thoroughly by *Lutz* (1886). *Bordoni-Uffreduzzi* (1888 *a*) termed the polar swellings arthrospores. Their germination to bacilli has been probably first seen by *Czaplewski* (1898). The occurrence of sporelike inclusions within what has been either regenerative bodies or gonidangia of the leprosy organism was recorded by *Babes* (1907). Very interesting pictures of the different reproductive organs of *B. leprae*, made by *Kedrowski* (1910), were reproduced as figure 37 on Plate J and as figures 153 and 154 on Plates XI and XII. Others published by *Meirowsky* (1914 *b*) are to be found on Plate XII (figs. 165 and 166) and on Plate XIV.

Liberation and germination of the gonidia produced within the threads and the gonidangia of *B. mallei* have been probably first discussed by *Semmer* (1895) as an analogous occurrence to the same type of reproduction of *B. tuberculosis*. *Marx* (1899) and *Conradi* (1900) saw only lateral development of the gonidia into buds and branches, and reached the conclusion that no spores were formed, because no resistance against heating could be ascertained. *Wladimiroff* (1903), however, pointed out that the granules formed by the rods can preserve the life of the species for a very long time, and he places them parallel to those granules (i. e. gonidia) studied by *N. K. Schultz* (1901) and by *Rothert* (1902) with *B. pestis* and numerous other bacteria. The rather high resistance which, according to *Lehmann* and *Neumann* (1912, p. 548), has been occasionally observed with *B. mallei* by *Bonâme*, who found that a temperature of 70° C. could be endured for 6 hours, and 90–100° C. for 3 minutes, clearly indicates that also in this case regenerative bodies, arthrospores, or microcysts may have exerted their influence. In the photographs made by *Carpano* (1913) of this organism, reproduced as figures 91–96 on Plate VIII, gonidia, gonidangia, and regenerative bodies are well discernible, while in regard to the occurrence of arthrospores and microcysts no definite answer can be secured, neither from the picture nor from the paper itself.

The gonidia of *B. diphtheriae* were considered by *Klebs* (1887) to be spores. According to *Cornil* and *Babes* (1890, Vol. II, p. 59) reproductive organs of comparatively high resistance against boiling water have been found by the latter author in 2 among 42 cases, but their exact nature was not determined. That the gonidia are not spores was emphasized against *Klebs* by *Escherich* (1894, p. 73), who in addition pointed out (p. 83) that the club-shaped cells should not be classed as sign of degeneration, because they develop in abundance on serum within 24 hours. Radiate and parallel growth shown by *B. diphtheriae* was declared by him (l. c., p. 87) to be caused by the germination of the "chromatine granules" to new rods. Good pictures of typical lateral regenerative bodies of this species have been published by *Bernheim* and *Folger* (1896) and by *Spirig* (1903). The last-named author's publications upon this subject (1899, 1903) give also valuable information upon occurrence and germination of gonidia and arthrospores. Liberation and upgrowth of diphtheria gonidia have been further recorded by *Cache* (1901) and by *Fedorowitsch* (1902). *Chester* (1901, p. 14) sees in them the cause of the resistance of diphtheria bacilli against drying; but it is more probable that regenerative bodies and arthrospores also in this case are of greater importance. Pure coccoid growth of diphtheria, observed by *J. Dale* (1910), *Balfour* (1911 *d*), and by *Park* and *Williams* (1914, p. 294), was evidently the result of round regenerative bodies multiplying as such for some time. In secondary colonies normal rods were seen to grow again by the first-named author. Interesting illustrations showing the various reproductive organs of B. diptheria may be found in *Bergstrand's* paper (1918).

What *A. Neisser* (1888) called the endospores of *B. xerosis* was obviously what we now call gonidia. Especially their lateral germinating while still within the rods, together with their moderate resistance against heating, leaves no doubt in this respect. What *Neisser* on the other hand calls gonidia are those clubbed cells to which this name was given by *Bollinger* (1877), when he first saw them with Actinomyces, which, however, when they are fully developed, become either gonidangia or regenerative bodies. The "sporogenous" pseudo-diphtheria bacillus described by *Simoni* (1898) owed its moderate heat resistance (80° C. for 10 minutes) probably to its ability to produce regenerative bodies or arthrospores, such as *Nakanishi* (1900*c*) found with his diphtheroid *Bac. variabilis*. A characteristic photograph made by the latter author was reproduced as figure 98 on Plate IX. Others published by *E. de Negri* (1916), showing gonidia and regenerative bodies of a Corynebacterium causing malignous granulom, have been reproduced as figures 99 and 101 on Plate IX and as figure 184 on Plate XV. The regenerative bodies were seen to reproduce either normal rods and threads or again budding round forms, as all such regenerative bodies are able to do; the latter, however, were mistaken by the author as being the growth of a Blastomyces.

The description of *Streptobacillus pellagrae* as given by *Tizzoni* and *Angelis* (1913–1915) contains sufficient data from which it may be concluded that gonidia, regenerative bodies, arthrospores, and microcysts have probably all been seen with this Actinomyces-like organism.

The so-called *Streptothrix cuniculi* of *Schmorl* (1891), which is identical with *Bang's* necrosis bacillus, has furnished instructive pictures of gonidia and gonidangia, which have been reproduced as figures 89 and 90 on Plate VIII. Both were found by *W. Ernst* (1902) to be somewhat more resistant than the vegetative cells.

Typical arthrospores, formed especially by segmentation of the aerial hyphae, have been observed quite regularly with probably all Actinomycetes, for instance by *J. Israël* (1878), *Gasperini* (1889), *Domec* (1892), *Garten* (1895), *Kedzior* (1896), *Rullmann* (1896), *Lachner-Sandoval* (1898), *E. Levy* (1902), *Neukirch* (1902), *Doepke* (1902), *Feistmantel* (1902), *Gilbert* (1904), *Schütze* (1908), *Krainsky* (1914), and others. Data referring to the liberation of the gonidia formed within the threads or in the clubs, which act occasionally as gonidangia, are not quite so frequent. They may be found in the papers of *J. Israël* (1878), *Mac Fadyean* (1889), *Bostroem* (1890), *Eppinger* (1890), *Crookshank* (1896, p. 437) and *Loele* (1908). Of special interest is the discovery made by *Hollandt* (1906) that a typical Actinomyces occasionally may develop micro- and macro-gonidia like a Crenothrix, and that these may also germinate within the widened sheath, giving rise to big bundles of new thin threads. While in this case the relationship

to the trichobacteria is very pronounced, connections with the other bacilli, especially with those producing endospores, are indicated by the tendency of some Actinomycetes to develop only one spore at the end of their side branches, as was observed, e. g., by *Schütze* (1908) and *H. U. Williams* (1912). Such "spores" may look very much like the common lateral regenerative bodies, but there is also the possibility that they may consolidate their content to a regular endospore, then showing a growth as was obtained by *Olsen* (1897) with *B. mycoides*. A characteristic sketch was reproduced as figure 20 on Plate F. What *Cozzolino* (1900) described as *Bac. filamentosus*, found in a case of pseudo-actinomycosis, exhibits also very clearly at the same time the morphological and physiological character of an Actinomyces and that of an endospore-forming bacillus. The same holds true in regard to a spore-forming Gram-positive organism, isolated by *Gruner* and *Fraser* (1912), which was said to have been "regarded by others as diphtheroid." *Mycobacillus synovialis*, isolated by *Chantemesse, Matruchot* and *Grimberg* (1917) from a case of arthritis, produced typical endospores which withstood 90° C. for 30 minutes.

Formation, liberation, and development of the gonidia of the trichobacteria are fundamentally the same as in the case of all other bacteria, but the usually much larger size of these reproductive organs made it more easy to find out that they really play an important rôle in the life cycles of these organisms.

The gonidia of Leptothrix have been studied by *Robin* (1853), *Hallier* (1865), *Miller* (1883), *Arustamow* (1889), *Dobrzyniecki* (1897), and *Beust* (1907). But it is hardly necessary to emphasize that not only the material used in these experiments has been by no means pure, the whole "genus" itself is obviously a mixture of large thread-like forms of very different bacteria.

Data relating to the gonidia of Crenothrix are to be found in the publications of *Cohn* (1870), *Zopf* (1879), *Giard* (1882), and *Rullman* (1907). Those of Cladothrix have been described by *Zopf* (1881), *Billet* (1890), and *Ellis* (1912), those of Beggiatoa by *Zopf* (1881–1883), *Engler* (1882), and *Zopf* (1895), and those of Clonothrix and of other iron bacteria by *Schorler* (1904), *Ellis* (1907–1910), and *Petschenko* (1913).

That the other types of bacterial reproductive organs, viz. regenerative bodies, arthrospores, and microcysts, as well as endospores, seem to be entirely absent in this group is probably to be explained by the strictly aquatic mode of life to which all these organisms have adapted themselves. To some extent the macro-gonidia may replace those more resistant bodies and help to preserve the life during dry spells. In addition, the comparatively thick sheaths of the trichobacteria are also enabled to act, in case of need, as protective organs.

3. CONCLUSIONS.

According to the details discussed on pages 90–162 the present status of our knowledge of the various modes and organs of bacterial reproduction can be defined as follows:

(1) Contrary to the monomorphistic theory, which only knows of one constant type of vegetative cell for every species, and of not more than one type of reproductive organ, the endospore, for merely one group of bacteria, it has been ascertained by numerous independent investigations that in reality all bacteria are not only distinctly pleomorphous in their vegetative growth, but are also able to produce various organs of reproduction. These are: Gonidia, regenerative bodies, exo- and endospores, arthrospores, and microcysts. All of them are made up of nuclear substances, which are reinforced by smaller or larger amounts of reserve material and protected by a more or less resistant membrane. Gonidia and regenerative bodies participate actively in the process of multiplication, whereas the other reproductive organs are in the first place resting forms. Gonidia, regenerative bodies, and probably microcysts, too, are produced by all bacteria, while arthrospores, exo- and endospores are less common; though there are indications that they will be discovered in many more cases, as soon as these problems are more thoroughly investigated.

(2) That gonidia play an important rôle in the multiplication and reproduction of bacteria has been discovered by *Perty* in 1852, and as the result of numerous later studies it has become

certain that they are common with all bacteria. Two to four or more gonidia may be produced within every cell; their formation is most abundant when the bacterial development is at its height. They may start growing while still within the parent cell, forming buds and branches or directly new vegetative cells within the old membrane, or they may be liberated either by actively piercing the cell wall or after the membrane has been partially broken or completely dissolved. Sometimes they remain temporarily attached to the parent cell by a comparatively long stem. Most of them, if not all, are enabled to display active motility. One long flagellum has been found as organ of locomotion. Their resistance against heating is not much higher than that exhibited by the vegetative cells, but they are more persistent under unfavorable environmental conditions, especially when exposed to drought. Direct upgrowth of the gonidia to new vegetative cells is not often noticeable in artificial cultures, on account of their minute size, their motility, and lack of suitable nourishment; but it has been observed occasionally with representatives of all groups of bacteria, e. g. with staphylo- and streptococci, Gonococcus, Meningococcus and Enterococcus, with *Bact. pneumoniae*, *typhi*, *coli*, *pestis*, *septicaemiae*, *pyocyaneum*, and *fluorescens*, with *Bac. anthracis*, *Megaterium*, *Azotobacter*, *Amylobacter*, *Chauvoei*, and *oedematis maligni*, with *Vibrio cholerae* and *proteus*, with various spirilla and spirochaetes, *B. fusiformis*, *Corynebacterium diphtheriae* and *mallei*, *Mycobacterium leprae* and *tuberculosis*, Actinomycetes, and with the various trichobacteria. Small clumps of gonidia may give rise to a distinctly star-like growth of bacteria, as it is very common with *B. radiobacter* and *radicicola*. Because of their variable chemical composition gonidia have been frequently mistaken as fat, volutin, or other reserve material. They have been also erroneously discarded as sign of plasmolysis when still enclosed in the parent cell, or as product of "granular decomposition" or of "partial bacteriolysis" after having been liberated by the dissolution of the cell wall. Within the blood and tissue, where they may replace the vegetative bacterial cells more or less completely, they have been confounded with hemoconia, cell granules, and other nonbacterial corpuscles. On and in the generally used cultural substrates they usually multiply as such, producing a very scant growth, which is only noticeable on very careful inspection. The higher resistance of the gonidia against chemical substances, like salvarsan, may become of importance in the medical treatment of chronic diseases.

(3) Not infrequently the bacterial cells increase considerably in size and undergo certain morphological changes before they begin to produce gonidia. This is the case when they become gonidangia, which are able to give birth to a large number of gonidia. The so-called giant forms of spherical, oval, spindle-, pear-, or club-shaped appearance, which usually have been lightly dismissed as "involution forms," have always proved to be gonidangia whenever they have been carefully examined. Formation of gonidangia has been discovered, for instance, with Gonococcus, Meningococcus, Enterococcus, Pneumococcus, *Streptoc. lactis*, *Bact. proteus*, *pestis*, *coli*, *typhi*, *aceti*, *radicola*, *fluorescens* and *cyanogenes*, *Bac. anthracis*, *Megaterium*, *Azotobacter* and *Chauvoei*, *Vibrio cholerae* and *proteus*, *Corynebacterium mallei*, *diphtheriae* and *necrophorum*, *Mycobacterium tuberculosis*, *Actinomyces hominis* and *bovis*, and with Crenothrix.

(4) Part of the gonidia of probably all species of bacteria, except those of the trichobacteria, are small enough to pass bacteria filter. They have been found to play an important rôle as filterable vira, "infective granules," or as so-called chlamydozoa, in diseases like trachoma, blenorrhoea non gonorrhoica, meningitis, scarlatina, lyssa, and various spirochaetoses. Multiplication as such seems to be the rule with the filterable gonidia, but under certain conditions, especially in the animal, reproduction of normal vegetative cells has been observed. The plasma in dead or dying cells of plants and animals generally offers the best opportunity for such an upgrowth; and the assumed transformation of cell granules into bacteria, which has been repeatedly proclaimed by adherents to the theory of heterogenesis, becomes easily explainable, as soon as the omnipresence and the peculiar behavior of the bacterial gonidia is taken into account.

(5) Those reproductive organs of the bacteria which have been called (pro tempore) regenerative bodies are produced either by the vegetative cell or by the symplasm. They are either globular, oval, pear-, or kidney-shaped, or more or less irregular, rod-shaped, and branched.

When developed by the vegetative cell, they may be found in a lateral or in a terminal position. The round regenerative bodies are able to multiply as such by fission and by budding, while the irregular forms either break up into round forms or reenter the symplastic stage. Pure growth of round regenerative bodies has been observed with *Streptoc. lanceolatus*, *Bact. pestis*, *septicaemiae*, *coli*, *cyanogenes* and *fluorescens*, *Bac. anthracis*, *Azotobacter* and *Amylobacter*, *Corynebact. mallei* and *diphtheriae*, *Mycobact. leprae* and *tuberculosis*. The uniform appearance of these bodies may sometimes cause difficulties in the diagnosis, especially in the case of diphtheria. Possibly several species of cocci will have to be reclassified as regenerative bodies of other species. This is very probable in regard to Nitrosococcus. Upgrowth of normal cells from the regenerative bodies is easily to be observed. It has been recorded with *Bact. pestis*, *coli*, *typhi*, *dysenteriae*, *radicicola*, *fluorescens*, and *cyanogenes*, *Bac. anthracis* and *Azotobacter*, *Vibrio cholerae* and other vibrios, *Spirillum rubrum*, various spirochaets, *Corynebact. mallei* and *diphtheriae*, *Mycobact. leprae* and *tuberculosis*. 1 to 4 sprouts may be produced by one regenerative body. While still connected with the parent cell the round regenerative bodies may be mistaken for products of plasmoptysis, and after being liberated for contaminating cocci, whereas the rod-like regenerative bodies of the micrococci may be confounded with bacilli or actinomycetes and the irregular regenerative bodies discarded as "involution forms." Instead of multiplying as such or germinating to new vegetative cells, the regenerative bodies occasionally develop to gonidangia or produce new vegetative cells by multiple fission. They are easily stainable, sometimes motile, and usually fairly resistant. The irregularities often observed in heating experiments with nonspore-forming bacteria are undoubtedly often due to the presence of regenerative bodies. Slow drying, a comparatively high concentration in the salt content of the substrates, and low temperatures have been repeatedly found to be favorable for developing a good growth of regenerative bodies.

(6) In some cases the round lateral or terminal regenerative bodies become unstainable and assume the character of so-called exospores, which take an intermediate position between the round regenerative bodies and the endospores. Their resistance is generally not higher than that of the former and distinctly lower than that of the latter. They have been observed with various vibrios and spirilla, as well as with the organisms of diphtheria, leprosy, and tuberculosis. In addition, however, they have been seen in a few cases with *Bact. pneumoniae*, *coli*, *typhi*, *acidi lactici*, *cyanogenes*, *Zopfii*, *fluorescens*, etc., and positive results secured in changing spore-free lactobacilli into spore-forming rods of the Mesentericus group and in reestablishing spore formation in asporogenous strains of butyric acid bacilli, make it very probable that bacteria producing such exospores represent, in fact, connecting links between nonspore-forming and spore-forming bacilli, and that their appearance in the cultures indicates the time when it becomes possible to induce a strain to develop its ability of endospore formation.

(7) Endospores can be produced besides by the vegetative cells, by regenerative bodies, as well as by gonidangia. The latter may contain two or more rudimentary endospores; and the formation of normal gonidangia is especially frequent in asporogenous strains of otherwise spore-forming bacilli. The polar endospores of *Bac. tetani*, *putrificus*, and of related species, are closely related to the terminal exospores. The same conditions which stimulate the development of the regenerative bodies are also favorable to endospore formation, which, however, usually takes place at a later time than the first-named process. If the endospore formation is suspended, the strains concerned become either similar to the regularly nonspore-forming bacteria, or to the Mycobacteria and Actinomycetes, which in their turn occasionally produce rudimentary endospores in their club-shaped gonidangia.

(8) Arthrospores are the result of a segmentation of the vegetative cells and of the transformation of these "joints" into fairly resistant bodies of globular shape. They are easily stainable and withstand drying better than heating. They are most frequent with Mycobacteria and Actinomycetes, certain Spirochaets and members of the Proteus group. Every arthrospore may produce 1 to 4 sprouts.

(9) Vegetative cells of bacteria sometimes transform themselves in their entirety into reproductive organs, called microcysts, by increasing their size, assuming a globular shape, and thickening their membrane. After a period of rest, they either resume directly their vegetative functions, or they germinate like spores, or they break up into 2, 3, or 4 segments which become vegetative cells. Sometimes they also transform themselves into gonidangia. Resistance and staining qualities are similar to those of the arthrospores, to which they are closely related. They have been found with micro- and streptococci, *Bact. proteus* and *aceti*, *Bac. anthracis*, *Azotobacter*, and other spore-forming bacilli, *Vibrio cholerae* and *proteus*, various Spirochaets and Mycobacteriaceae, and probably will be seen within all groups of bacteria, as soon as this point has received more attention.

III. FORMATION OF THE SYMPLASM AND THE REGENERATION OF CELLS.

1. GENERAL DISCUSSION.

Our observations relating to that part of the life cycles of the bacteria which we proposed to call the symplastic stage have been summarized in our first preliminary paper (*Löhnis* and *Smith*, 1916 *a*, p. 700) as follows:

> All bacteria studied live alternately in an organized and in an amorphous stage. The latter has been called the "symplastic" stage, because at this time the living matter previously inclosed in the separate cells undergoes a thorough mixing either by a complete disintegration of cell wall, as well as cell content, or by a "melting together" of the content of many cells which leave their empty cell walls behind them. In the first case a readily stainable, in the latter case an unstainable, "symplasm" is produced.
>
> According to the different formation and quality of the symplasm the development of new individual cells from this stage follows various lines. In all cases at first "regenerative units" become visible. These increase in size, turning into "regenerative bodies" which later, either by germinating or by stretching, become cells of normal shape. In some cases the regenerative bodies also return temporarily into the symplastic stage.
>
> The life cycle of each species of bacteria studied is composed of several subcycles showing wide morphological and physiological differences. They are connected with each other by the symplastic stage. . . . The transformation of spore-free into spore-forming bacteria seems to be dependent on the conditions acting upon the symplasm and regenerative bodies.

We pointed out in addition (*Löhnis* and *Smith*, 1916 *b*) that the facts recorded would certainly not have appeared so new and extraordinary as they did, if it had not (as a result of the prevailing "simplicity" theory) become a general habit to discard indiscriminately all evidence offered by the bacteria in this direction as being "merely dirt," or "simply slime," or "only detritus" resulting from bacterial "autolysis."

Very few references could be given at that time. But, as it was the case in regard to the pleomorphism of the bacteria and their different types of reproductive organs, search of the literature has furnished additional proof in abundance. The discussion of these facts, as recorded in the literature, though entirely neglected by the bacteriological textbooks to-day, will show anew how thoroughly modern bacteriology must be revised, before it will rest again on the solid ground of actual facts observed, instead of clinging to a narrow dogmatism, as developed during the last decades.

What we propose to call "symplasm" has already received several names. *Pineau* (1845) spoke upon a "substance granuleuse," *Perty* (1852, p. 106) about an "in Schuppen angeordnete Punktsubstanz," which occasionally formed globular agglomerations. *F. Cohn* (1853) adopted the term "zoogloea." *Lankester* (1876) furnished an excellent contribution upon "macroplasts or reproductive disks." *Haberkorn* (1882) introduced the expression "Bacteriophytom." *Marpmann* (1884) called the process "Protoplasma-Bildung." *W. Winkler* (1899) and *Almquist* (1917) used the name "plasmodium," the first-named author also the new term "Bakterioblast." *Růžička* (1903) classed the "zoogloea" as a "syncytium," and *Maher* (1910–1913) called the symplasm of the tubercle bacilli their "matrix."

We would, of course, readily give preference to one of these older terms if it would be equally distinct or better than ours. But "substance granuleuse," "Punktsubtanz," "Protoplasma-Bildung," "syncytium" and "matrix" can hardly come under consideration. The term "zoogloea" is being used so generally for all slimy agglomerations of bacteria that it has lost its specific meaning. The expression "plasmodium" implies motility, which is noticeable only in some cases. The "macroplast or reproductive disk," as described by *Lankester*, on the other hand, refers to a special discoid type of symplasm, which is a rather rare occurrence. So only *Haberkorn's* "bacteriophytom" and *W. Winkler's* "bacterioblast" would remain for

eventual adoption. But the latter term is very liable to collide with *Perty's* "blastia" (i. e., gonidia), and the former expression has been never used as far as I know except in a short preliminary paper, and it is hardly to be disputed that the terms "symplasm" and "symplastic stage" are more descriptive and more convenient.

The use of these new terms seems to be preferable also because of their adaptability to analogous occurrences in the life of other organisms. Some facts will have to be recorded on the following pages which indicate that undoubtedly with many of the lower organisms, but probably with the higher organisms, too, the symplastic stage of life plays an important, though hitherto little known rôle. As far as microörganisms come into view the sentence "Omnis cellula e cellula" is undoubtedly only partially true. But also with the higher organisms it does not seem to be so generally applicable as is often assumed.

That bacteria live alternately in various cell forms and in the amorphous symplastic stage, and that this fact furnishes the explanation of bacterial pleomorphism, as well as the experimental basis upon which the life history of the bacteria can be studied much more thoroughly and successfully than has been possible thus far, these conclusions apparently have not been reached before by any other author, evidently because even those who paid attention to the symplastic stage have worked with only one or a few species and had no opportunity to compare and unite their results with those secured by others, because nobody has ever tried to collect these data. The following discussion of the discovery of the symplastic stage will show conclusively how well our new observations agree with those secured already by earlier authors mostly at a time when the eyes were not yet mistrained to see in the microscope only the "normal, typical, legitimate" forms, and to overlook persistently all that which does not fit the theory.

(a) THE DISCOVERY OF THE SYMPLASTIC STAGE.

In the "Histoire naturelle des zoophytes" of *Dujardin* (1841, p. 20) the following passage is of interest:

> Quand . . . un infusoire n'est plus dans des conditions favorables à son existence, il se décompose par diffluence, c'est-à-dire que la substance glutineuse dont il est formé s'écoule en globules hors de la masse, laquelle, si les mêmes circonstances continuent à agir, se décompose tout entière . . . mais si par une addition d'eau fraîche ou d'un liquide convenable on change ces circonstances funestes, la reste de l'animalcule reprenant sa vivacité primitive, recommence à vivre sous une forme plus ou moins modifiée.

The "Recherches sur le développement des animalcules infusoires et des moisissures" by *Pineau* (1845 *a*) were more specific and more comprehensive. As the beginning of microscopic life he always found on the surface of organic substances submerged in water "une substance granuleuse, qui précède toujours l'apparition des êtres organisés des infusions, tant animaux que végétaux." He observed continuously the transformation of this granular substance into first immotile, later motile, bacteria and protozoa, as well as into molds. That he accepted this transformation as heterogenesis was, of course, not correct, but in agreement with the consensus of opinion at that time. His drawings, reproduced as figure 78 on Plate Q (from original figs. 8–27 on Pl. 4 bis), are of great interest, as is the following description given in a "Supplément" (1845 *b*) to these "Recherches:"

> On remarquait, en premier lieu, de petits amas de granulations dont les contours commençaient par être diffus; peu à peu ces amas devenaient plus nettement circonscrits, et ils finissaient par acquérir l'aspect de véritables monades, d'abord immobiles, puis douées de mouvement.—Le phénomène primitif du développement des cellules et des infusoires consiste essentiellement en une agglomération de granules.

Though primarily relating to other microörganisms, these observations are equally correct with regard to the regeneration of bacterial cells from the symplasm, while it must be left to mycologists and protozoologists to decide how far these old findings will be supported by the results of modern investigations upon the life history of these other microörganisms.

Perty (1852), to whom we owe the earliest detailed information upon the different types of bacterial reproductive organs, has also furnished very clear descriptions of the part played by the symplastic stage in the life of protozoa, as well as of bacteria. His observations upon

the formation of Podophyra and Actinophrys cells were illustrated by the drawing reproduced as figure 79 on Plate Q (from original figs. 9 and 10 on Pl. VIII) and described as follows (p. 74):

Im Winter 1848 nahm ich zum ersten Male Podophyra libera wahr, und zwar 5 grössere Exemplare von etwa 1/50‴ Durchmesser lagen an einer Masse aus feiner Punktsubstanz gebildet, in welcher bis zu 1/400‴ herab kuglige Zusammenballungen von Molekülen lagen, von welchen die grösseren immer deutlicher die Beschaffenheit teils von Podophyra, teils von Actinophrys annahmen . . . In den kleinsten dieser Zusammenballungen waren erst nur wenige Moleküle unregelmässig und locker vereinigt, in den grösseren zahlreichere zu regelmässiger Kugelgestalt mit allmählich sichtbar werdenden Strahlen; von diesen grösseren zeigten ein paar zitternde, hin- und herrückende Bewegung.

In old infusions, filled with bacteria and protozoa, *Perty* saw the motile bacteria agglutinate and transform themselves into immotile, crumbly, granular clumps of various shape, which when transferred into fresh solutions gave new bacterial growth (l. c., p. 109, 110). Most characteristic and essentially very correct is the following passage (l. c., p. 113), although the heterogenetic standpoint, which *Perty* shared with his contemporaries, is clearly noticeable:

Die organisierten Körper scheinen sich bei der Fäulnis aufzulösen und in eine unaussprechlich feine Punktsubstanz umzuwandeln, welche nicht in dem lebenden Organismen vorgebildet, sondern schon eine neue Construction ist. Diese Punktsubstanz (welche manchmal Neigung zeigt, sich in kuglige Agglomerate zu ballen . . . , auch bisweilen zitternde Bewegung zeigt) ist aber nicht eine durchaus homogene, sondern innerlich schon wieder verschiedentlich determiniert, so dass aus ihr Wesen verschiedener Art, namentlich Vibrioniden und Monadinen entstehen können.

Evidently the same fact has been studied by *F. Cohn* (1853) when he described the "Gallertkugeln" present in old bacteria infusions as being "ganz verschieden von den oberflächlichen Bakterienhäuten." "Zoogloea termo" was defined as "massae mucosae globosae, uvaeformis," and that later the floating films of bacteria usually have been called zoogloea is obviously not in accordance with these original findings and statements.

When *Robin* (1853) described his *Leptothrix buccalis* he also mentioned that its long cells were "réunis généralement, par la base, à une gangue amorphe granuleuse," which he thought to be the detritus of food remnants in the mouth, which, however, as will be seen later, may have been just as well flakes of symplasm not yet transformed into new threads. Later (1871) in his "Traité du microscope" the French author wrote concerning the same subject (p. 927):

Les nombreux granules, très fins, de volume uniforme, que le microscope montre dans le mucus, à la surface des cellules épithéliales, linguales, intestinales, dans beaucoup de déjections intestinales, ont un aspect très characteristique; elles ont, d'un auteur à l'autre, reçu des noms très differents (zoogloea, couche muqueuse primordiale, pellicule proligère).

It is, of course, not to be denied that this, as well as the earlier quotations given above, may also relate in part or wholly to agglomerations of bacterial gonidia and perhaps of regenerative bodies. Instruments and methods available at that time did not allow a clear distinction; even to-day such a task is not always easy. But the data to be given on the following pages will show that it is at least very probable that the symplastic stage has been already discovered by these early authors.

In the same manner as the bacterial gonidia proved to be of great value in supporting (apparently) the old theory of heterogenesis, as was discussed on pages 148–150, so naturally the amorphous agglomerations of bacterial symplasm can be mistaken even more easily for any other kind of vegetal or animal "slime," which by its ability to produce bacteria may be readily accepted as decisive, though in fact deceiving, proof of bacterial heterogenesis. This is the obvious reason why this hypothesis could be adhered to until recently by various authors. Their observations were usually fairly correct; but the absence of adequate knowledge upon the symplastic stage of the lower organisms allowed them to indulge in lofty speculations and made it impossible, on the other hand, to explain the facts recorded in an intelligent manner.

It was pointed out before (*Löhnis* and *Smith* 1916 *a*, p. 699) that especially those much doubted and disputed findings recorded by *Bastian* (1872–1914) now are coming under entirely new aspects. Many of his pictures prove beyond doubt that he, indeed, observed very carefully the upgrowth of cells from the symplastic stage. Those reproduced as figures 205–208 on Plate XVI (from original figs. 11 B and C, 12, and 13 on Plates IV and V, 1905, and fig. 33 A on Pl. XI, 1907) are especially characteristic and worthy to be compared with *Perty's*

and *Pineau's* drawings, as well as with other photographs shown on the following plates. That *Bastian's* experiments were faulty in many respects needs not to be pointed out, as he declared himself (1905, p. 184):

I emphasize the fact that the researches which I am about to detail have no pretence to be conducted in ways that are proper and usual in the great bulk of bacteriological inquiries.

Sterilization was often incomplete, and what he observed may sometimes have been dead cells, occasionally also silica conglomerates, though undoubtedly not so generally as *Payne* (1916) and *Onslow* (1917) are inclined to assume, as *Bastian* himself (1907, pp. 247, 275) was fully aware of this possible source of error. He also reported (1872, Vol. II, p. 209) that he saw the bacteria disappear, dissolving themselves into "a whitish refractive and homogeneous protoplasm," and more recently he added other interesting details concerning the formation of the bacterial symplasm and the regeneration of cells from it, which will be considered later. In view of all this, it is certainly not easy to understand how he could continue to assert (1903), p. 3):

The lower forms of life, both animal and vegetal, are ever springing up anew . . . from matrices wholly unlike themselves.

That *Bastian* did not become aware of the fact that he merely was dealing with the two manifestations of bacterial life is especially surprising when one considers what a great number of publications has been issued soon after his first book came out, all discussing the ability of the bacteria to form these "matrices" and to spring forth from them. *Osler* and *Schäfer* wrote in 1873:

In vielen Krankheiten befindet sich in dem Blute eine kleinere oder grössere Anzahl farbloser, granulierter Massen, die Grösse der weissen Blutkörperchen oft um viele Male übersteigend, und unter starken Vergrösserungen aus kleinen, blassen Teilchen zusammengesetzt erscheinend.

They also observed under the microscope that these substances were able to produce threads and motile bacteria.

That the "*Microsporon septicum*," described by *Klebs* (1872), behaves in an analogous manner was noticed by this author (1873), when he studied its growth in gelatin kept in Geissler's chamber. Besides regular colonies made up of rods, homogeneous yellow agglomerations were seen, sometimes spherical, sometimes of irregular outline showing protrusions "similar to the pseudopodia of amoebae." These plasmatic masses were seen to produce new bacteria, and, on the other hand, bacteria were seen to fuse together into such homogeneous plasma. Diphtheria cultures were found (*Klebs*, 1875 *a*) to contain small rods and "dark brown masses," homogeneous in the center, finely granulated at the outside, which were seen to transform themselves gradually into small bacilli, first at the edge, later in the center, too. In cases of endocarditis the same author (*Klebs*, 1878) noticed that the hyalin substances present were formed by micrococci. Stained with hematoxylin small granules became visible at the outside, while the center proved to be homogeneous, composed of round and of irregular agglomerations. Figure 210 on Plate XVII is a reproduction of *Klebs's* drawing (original fig. 3 on Pl. II). The author concludes:

Es scheint . . . nicht bezweifelt werden zu können, dass jene oft erwähnte hyaline Masse zum Teil aus den umgewandelten Schistomyceten besteht.

Furthermore, in 1883 *Klebs* pointed out in regard to tuberculosis, that *Koch's* bacilli are only one phase in the development of the causative agent, which presents itself in young inoculations as finely granulated masses, which later give birth to the bacilli. The following statement (1883 *b*, p. 131) is of great interest:

An isolierten Tuberkeln, welche in lufthaltigen, mikroskopischen Kammern der direkten Beobachtung zugänglich gemacht werden, sieht man diese feinkörnigen Massen aus dem Gewebe selbst hervorwachsen. Dieser Umstand sowie ihr Auftreten in den Kulturen beweist, dass sie einen integrierenden Bestandteil des Tuberkelorganismus darstellen, und diese Auffassung wird noch dadurch bestätigt, dass wie schon von *Koch* zugegeben, seine Bacillen in offenbar frisch wuchernden Tuberkeln oftmals nur in überaus geringer Anzahl gefunden werden. Andrerseits zeigt ihr constantes Nebeneinandervorkommen auch in möglichst reinen Culturen (ich habe die Anwesenheit der körnigen Massen auch in einer von *Koch* selbst hergestellten Cultur nachweisen können), dass beide Bestandteile gemeinsam zu dem Wesen des Tuberkelorganismus gehören.

The large hyalin globules noticeable in cases of rhinoscleroma within and without the cells were declared to be (*Klebs*, 1887, p. 271) "wahrscheinlich Überreste abgestorbener Bacillenhaufen."

Another set of analogous observations has been furnished simultaneously by *Letzerich*. In cases of diphtheria he found (1873–1876) large spherical or pear-shaped plasmatic bodies, which apparently were formed by a melting together of the bacilli lying side by side in the membrane, and which produced in their turn small coccoid bodies, which later were set free by rupturing the membraneous outside of these cyst-like bodies. Blood cultures furnished in addition large irregular agglomerations, sometimes showing amoeboid movements, occasionally uniting with each other or dividing into several parts. They also transformed themselves into "cocci," first at the edge, later in the center. The drawings reproduced as figure 80 on Plate R (from original figs. 5–10 on Pl. XII, 1876) look very queer and suspicious at the first moment. But we will have to consider later so much additional evidence, proving beyond doubt that, indeed, genuine bacteria may behave sometimes very much like Myxobacteria and Myxomycetes, that these drawings may find a place here, despite the fact that the trustworthiness of *Letzerich's* findings is undoubtedly much impaired by the manner in which he supported the most extravagant hypotheses à la *Hallier*. The plasma spheres of diphtheria, for instance, are said to develop occasionally to fungus spores, and the diphtheria organism is declared to be a "Tilletia diphtheritica." Obviously under *Klebs's* influence, a somewhat more sober standpoint was later taken by *Letzerich* (1880), who now also studied under the microscope in Geissler's chamber the transformation of the spherical "wax-like" masses of the "plasma cells" into normal colonies of bacteria.

Billroth (1874) found amorphous agglomerations in broth, serum, and various infusions, which he thought to be perhaps "plasmodia" and, on account of their showing occasionally a development of coccoid bodies, to be possibly the cause of a "eigentümliche Coccosentstehung aus einem zu einer Platte verschmelzenden Plasma" (1. c., p. 10). On the other hand, he also observed that in old cultures of bacteria and algae a dissolution of the cells took place. But apparently he did not think of any connection existing between these two facts.

In cases of variola *Weigert* (1875) discovered in the blood, as well as in various organs of the body, peculiar, granular, spherical, or cylindrical "Bakterien-Schläuche," which were embedded in amorphous masses produced by the surrounding cells, and which later themselves disappeared completely, becoming entirely homogeneous, or transforming themselves into smallest granules.

Probably the most important among the early contributions to the knowledge of the symplastic stage of the bacteria has been made by *Lankester* (1876) in the course of his investigations upon the red sulphur bacteria (*Bact. rubescens*). He noticed that repeatedly, always when the food supply became low, "macroplasts" or "reproductive discs" were formed, which under high magnification (×1,100) presented themselves to be either "truly homogeneous" or having a "minutely punctuate structure," or being regular colonies of globular cells, surrounded by a membrane. Further studies showed that the minute granules "indicate so many new units or centers of organization," and it is stated (p. 36):

> Just as we find exceptional cases in animal and vegetable cells in which a mass of protoplasm gives rise simultaneously to numerous nuclei, each of which becomes surrounded by a segregated mass of protoplasm and produces a numerous cell progeny by multicentral segregation, so it appears that in the large discoid macroplasts of Bacterium rubescens a formation of innumerable new plastids occur—not by a progressive division into two, four, eight, etc.—but by a simultaneous multicentral segregation.

It is, indeed, highly surprising, how such an excellent description of this very interesting process, which was accompanied by so characteristic pictures as those reproduced as figure 209 on Plate XVI, could later be entirely forgotten, and despite the various studies made by *Winogradsky* and by *Molisch* with the same or similar organisms nothing more was learned about these macroplasts, which, it is true, have no place within the narrow limits of the rigid dogma of bacterial monomorphism and constancy, which both authors felt obliged to defend vigorously. And yet, in addition to all other evidence, it is only necessary to compare *Lankester's* picture with the photograph of a Nitrosomonas "zoogloea" made by *Winogradsky* (1892),

which is reproduced as figure 270 on Plate XXI, to show at once that despite their conspicuousness it must have been difficult to overlook these things persistently.

But it is not less surprising that *Robert Koch*, too, just as he first saw and photographed the gonidia and regenerative bodies of various bacteria and later forgot all about them (cf. pp. 92 and 94), gave a faithful picture of the partially homogeneous, partially granular agglomerations of the symplasm, found by him in spreading abscesses in rabbits, on Plate I of his "Untersuchungen über die Aetiologie der Wundkrankheiten" (1878), reproduced as figure 211 on Plate XVII (from original fig. 8), but afterwards never returned to this subject. And not only this; he did not even hesitate (1884 *a*, p. 54) to "explain" *Klebs'* (1883) observations concerning the formation of symplasm by the tubercle bacilli by simply asserting that the unstainable masses seen by this author had been "serum." A glance at the quotation printed above suffices to demonstrate the utter inadequacy of this "explanation." An equally superficial "explanation" was furnished by *Loeffler* (1884, p. 431) in regard to *Klebs'* and *Letzerich's* discoveries. Their homogeneous plasmatic agglomerations are simply declared to have been normal bacterial "colonies" in the gelatin used, despite the very distinct differentiation, made by *Klebs* (1873) as well as by *Letzerich* (1880), between colonies and plasmatic "wax-like" agglomerations. Moreover, neither *R. Koch's* nor *Loeffler's* assumption gives any explanation for those homogeneous or granulated masses found by *Klebs*, *Letzerich*, *Weigert*, *Osler* and *Schaefer*, as well as by *R. Koch* himself, to be present within the body.

Nevertheless, from now on the symplastic stage of the bacteria was excluded from the "legitimate" bacteriology of *R. Koch* and his followers, as was the case with pleomorphism, with the gonidia, and with the regenerative bodies of the bacteria. During the following decades, however, many confirmative results have been gathered by independent workers, which, taken together, leave no doubt that the omission from the bacteriological textbooks of all data pertaining to this subject is quite unwarranted.

In 1880 and 1882 *G. A. Hansen* wrote upon "brown elements" occuring in leprous tissue which are filled either with a finely granulated mass or with normal rods. His descriptions, as well as his drawings, resemble those of *Klebs* and of *Letzerich* very closely, and they found an early confirmation in *Babes'* leprosy studies (1883), wherein it was ascertained that the tissue often contains "une masse homogène et granulée" while practically no microbes are visible.

Albrecht (1881) noticed in the course of his investigations upon the development of *Spirochaeta Obermeieri* that besides motile granules (gonidia) and spirochaets also "unförmliche Haufen von dunklen Punkten" were present in the blood, which continually changed their form.

At the same time *Fokker* (1881) noticed that *Bac. anthracis* produced within the body a similar finely granular "detritus," and further investigations (1882) led to the result that in 300 inoculation tests on mice in no instance bacilli were found, three times coccoid bodies, and in all cases in blood and liver

eine bedeutende Menge grobkörniges Material, das sich gar nicht färben und weder durch Alkohol noch auch durch Erhitzen am Glase ankleben liess.

Twenty years later *Fokker* (1902, pp. 16–26) returned to this subject, reporting that he found the "dissociation" of the anthrax bacilli in water, serum, and in broth to be especially pronounced during the first hours after having made the transfers. Comparative plating on agar gave, for instance, the following number of colonies:

At the beginning	721	2,000
After 1–2 hours	0	8
3–4 hours	3	.....
1 day	10,300	780
2 days	.....	3,500

Concerning the regeneration of the bacilli it is assumed

dass sich aus diesem gelösten Plasma Granula verdichten und aus diesen Granula wieder Bacillen hervorgehen, oder aber, dass nachdem sich ein osmotisches Gleichgewicht ausgebildet hat, das Plasma wieder von den Gerüsten aufgenommen wird.

The latter possibility is considered to be more probable. As will be seen later, in fact both modes of reconstruction may take place.

Owing to *Fokker's* adherence to the theory of heterogenesis, it was unavoidable that in the same manner, as he accepted the participation of the gonidia in the reproduction of the bacteria as full proof of the heterogenetic origin of these organisms (cf. p. 149), so also the symplastic stage had to serve as an important part of his "neue Bakterienlehre." The "milk granules" and the flakes of "casein," which gave him (1901) "new" bacteria, have been undoubtedly flakes of symplasm and regenerative bodies growing out of it, as was discussed in our first preliminary paper (1916 *a*, p. 692). The photograph of such a flake of symplasm, studded with the round regenerative bodies of *Streptoc. lactis*, taken from milk, has been reproduced as figure 214 on Plate XVIII (from original fig. 33, *Löhnis* and *Smith*, 1916 *a*).

In his studies upon the "microzymas" *Béchamp* (1883) naturally also encountered the symplasm and saw it taking part in the reconstruction of cells. A characteristic drawing of his (original fig. 5, Pl. I) showing the regeneration of yeast cells from the agglomerations of "microzymas" in vinegar has been reproduced as figure 81 on Plate R. It should be compared with the analogous pictures made by *Pineau, Perty* and *Bastian* (reproduced as figs. 78 and 79 on Plate Q, and fig. 206 on Pl. XVI). The description given by *Béchamp* (l. c., p. 472) is worth quoting:

> La mère de vinaigre est membraneuse et les microzymas y sont réunis par une matière unissante, hyaline. À mesure que les cellules apparaissent, les choses se passent comme si les microzymas consommaient en même temps et les aliments qui leur sont fournis par le bouillon sucré et la matière hyaline qui les unit, et s'agglomérant, sécrétaient la matière qui forme l'enveloppe, les parois de la cellule.

Very similar observations have been recorded by *Cocardas* (1884); and his drawings are much alike to those of the earlier authors. But the abstruse "nouvelles idées" presented in his paper make it, indeed, quite conceivable why the French "Société de Botanique" did not accept his contribution for publication.

That the "Bacteriophytom" of *Haberkorn* (1882) is identical with what we call symplasm has been mentioned above. It was always found in old cultures as large, compact, oval, or globular bodies with granular surface of different refraction, producing either "Körnerhaufen" (i. e. agglomerations of round regenerative bodies) which later grew up to rods, or directly regenerating numerous young bacilli which made the "Mutterboden" look "wie gestrichelt." Two of our photographs, reproduced as figures 256 and 257 on Plate XX (from *Löhnis* and *Smith*, 1916 *a*, original fig. 15, and 1916 *b*, original fig. 48), may demonstrate the correctness of these early observations.

Marpmann (1884, p. 44) was equally right when he wrote:

> Unter Umständen löst sich eine ganze Familie oder ein Enzelwesen ganz in Schleim, Protoplasma auf. . . . Dieses Protoplasma kann wahrscheinlich unter günstigen Umständen wieder die ursprüngliche Spaltpilzform hervorbringen. Man findet solche Schleimmassen in allen älteren Kulturen, daher ist es wahrscheinlich, dass der Lebensprozess der Spaltpilze mit der Protoplasma-Bildung abschliesst. . . . Ob diese Schleimbildung stattfindet, wenn Spaltpilze in den gesunden tierischen Körper gelangen und sich nicht normal entwickeln können, ist nicht bewiesen, dagegen sehr wahrscheinlich.

"Les amas enkystés de bacilles" which according to *Babes* (1883) occur in "les tissus scléreux de tuberculose," and which were often found not to contain any rods, but instead of these "grains bien colorés, ronds ou cubiques, se rapprochant de l'apparence des sarcines," may well have been in part or wholly agglomerations of symplasm transforming itself into regenerative bodies. "La tuberculose zoogléique" of *Malassez* and *Vignal* (1883–1884) with its characteristic "masses zoogléiques de microcoques," which in old lesions reproduce the typical bacilli of *R. Koch*, eliminates all doubt, if there still should be any, that *Klebs'*, not *Koch's*, findings were the more correct and more complete ones. In their first paper the French authors state explicitly:

> Il existe une parenté entre nos zooglées et les bacilles de Koch.

But in the second one they are again somewhat doubtful in regard to this point, and this probably was the cause why later authors sometimes declared this type of tuberculosis to have been pseudo-tuberculosis. The staining reaction of the "zoogloea" was found by *Malassez*

and *Vignal* (1884) to be variable, and it is pointed out specifically that such clumps may have often been mistaken for giant or mast-cells. *Amrusch's* (1886) observations "Über eine Zoogloea-Form der Tuberkel-Organismen" confirm fully the earlier discoveries. It is true that the German author was very anxious to point out that his findings had nothing whatever to do with those of the Frenchmen, because "his" zoogloea took the stain (weakly), while that of *Malassez* and *Vignal* is declared by him, quite contrary to their own statements, to have been unstainable. A study of his paper, however, reveals clearly, that he once more saw the melting together of rods to slimy, granular agglomerations, from which later new bacilli grew out; in addition to this he noticed, when studying the living material, that within these clumps continuous movements took place and the outlines changed frequently, exactly in the same manner as had been observed before by *Stricker*, whose results obtained with putrefying bacteria are reported in this paper.

In cases of "pseudo-tuberculosis" of guinea pigs *Eberth* (1885) found that instead of rods "micrococci" were present, especially in the liver, occurring in large clumps, stainable at the edges, unstainable in the center, just like *R. Koch's* septicaemia "micrococci." *Nocard* (1889) recorded similar facts, and *Zagari* (1890) thought himself to be justified, because he, like *Eberth*, *Pfeiffer*, and others, obtained slimy agglomerations of short rods (0.4×0.8–1.0μ), which he incorrectly calls micrococci, in cases of pseudo-tuberculosis of rodents, to "explain" the "tuberculose zoogléique," found by *Malassez* and *Vignal* in man, as having been "merely pseudo-tuberculosis," though he, of course, never saw the Koch bacillus develop from the zoogloea, as these authors had seen.

That spirilla may also enter the symplastic stage has first been recorded by *Finkler* and *Prior* (1884–1885). Old cultures of their vibrio furnished "körnige Massen, die man als Detritus bezeichnen könnte," which, however, transferred into new substrates (broth or gelatine) after 12–24 hours produced "ausserordentlich kleine Kommabacillen," slowly growing up to their normal size. Soon afterwards *Weibel* (1887) added to his description of a "Vibrio aus Nasenschleim" the following footnote (p. 469):

> Eine eigentümliche Beobachtung habe ich noch nachträglich gemacht. Präparate von einer 4 Wochen alten Agar-Cultur zeigen nirgends mehr intacte Stäbchen oder Fäden, sondern nur einen kleinkörnigen Detritus, der die Farbe schlecht annimmt—also das Bild abgestorbener und zerfallener Bakterien. . . . Wohl characterisierte Sporen findet man auch nicht. Und doch, wenn man aus diesser Masse in gewöhnlicher Weise auf neuen Agar überträgt, so wächst in 1–2 Tagen die üppigste Cultur. Nähere Untersuchungen hierüber werde ich nicht versäumen.

But in his later publication he did not touch this point again. Maybe he did not like to be attacked by *R. Koch* and his pupils in the manner as was done to *Finkler* and *Prior*.

Dowdeswell (1889–1890) found in his cholera cultures small masses of minute granules and sometimes of fine short filaments. Some of these masses were seen slowly moving around in an amoeboid or gyrating manner. The small granules contained therein reproduced vibrios and filaments by uniting and filling the cells, and it is also reported that—

> the cells of the filaments, in masses large or small, are seen to actually coalesce or be fused together, as if they were evolved out of a mass of primitive plasma.

Curiously enough, also this British author evidently was unacquainted with the analogous discoveries made by *Lankester* and the other early authors, who all had observed the same occurrence and had described it with practically the same words.

P. Ernst (1888) reported that he got prompt development of *Bac. xerosis* from the small granules visible in a "krümligen, pulpösen Einbettungsmasse," which was the only thing present in 3-months-old cultures. Already some years earlier *Hauser* (1885) had seen that the rods and filaments of his Proteus transformed themselves often quickly (within 24 hours) into a finely granulated zoogloea, wherein only minutest globules remained visible, and that later new rods and threads "germinated out of the clumps of zoogloea."

In the course of his leprosy studies *Lutz* (1886, p. 81) made the interesting drawings reproduced as figure 82 on Plate R, of what he, like later *P. Ernst*, called "Einbettungsmasse," and of which he says:

> Diese Einbettungsmasse spielt bei der Formation der leprösen Neubildung eine wichtige Rolle, da sie den grösseren Teil der Stäbchencolonie bildet.

Sometimes these slimy agglomerations looked to him like—

aufgelöste Nebelflecke in Gestalt durchsichtiger Wolken, die aus lauter Pünktchen und Tüpfchen bestehen.

In cases of rhinoscleroma *Cornil* and *Alvarez* (1885) found not infrequently within the giant cells, replacing the bacilli smaller or larger hyalin masses, which were stained more easily than the encapsulated bacilli. Good pictures of all intermediate stages are given in the paper, but the authors do not reach a definite conclusion, whether these masses were produced by the bacteria themselves or by the cells under the influence of the bacteria. That *Klebs* (1887) made analogous observations, has been mentioned before (p. 170), and in the textbook of *Cornil* and *Babes* (1890, Vol. II, p. 326) the question is taken up once more, but again no final answer is given, though the authors say (l. c., p. 327):

Existe-t-il une relation de cause à effet entre les microbes du rhinosclérome et les masses hyalines des grandes cellules? Cela nous paraît vraisemblable.

Billet (1890) made some interesting remarks upon the rôle played by the "état zoogléique" in the life history of *Cladothrix dichotoma* and of other bacteria, and stated (p. 215):

L'état zoogléique définitif . . . . nous semble devoir constituer un caractère de premier ordre pour la différenciation des diverses espèces de Bactériacées.

Experiments with bacteria from the root nodules of leguminous plants furnished *Frank* (1890) sometimes peculiar colonies, formed by small motile "Schwärmer," which later developed to "Zoogloeahaufen," wherein the small bodies were visible "in kochender Wimmelbewegung." Figure 83 on Plate R illustrates these different types of growth (reproduced from original figs. 34 *a–c* on Pl. VIII).

Similar colonies were seen by *Prazmowski* (1890) in pure cultures of *B. radicicola*, as well as in the nodules themselves; they were surrounded, however, by a comparatively solid membrance, which was left behind, when the bacteria were liberated. The drawings made by *Morck* (1891), reproduced as figure 84 on Plate S (from original figs. 3 and 12 *e* and *f*), showing the clumps of plasma, which he saw to be formed by a melting together of the "bacteroids" in the root nodules of various legumes, make an interesting counterpart to *Lutz's* leprosy pictures, reproduced as figure 82. These clumps were found to be able to reproduce small rods, and on the other hand "granulated protoplasm" was seen to be present in the youngest part of the nodules, here forming small coccoid bodies, which later developed to normal bacilli.

If all the foregoing observations had elicited the interest, which they actually deserved, the important discoveries made by *Thaxter* (1892–1904) upon the Myxobacteriaceae undoubtedly also would have been valued by the bacteriologists in a more adequate manner, than it was generally their fate. Instead of being left aside as some curiosity, *Thaxter's* studies fully deserve to be kept in mind when planning thorough bacteriological investigations in the future. A short discussion of the relations existing between bacteria, myxobacteria and myxomycetes will be given at the end of this historical resumé.

In human, as well as in bovine, actinomyces "grains" *Crookshank* (1896) found the central portion "composed as a rule of a structureless core," but *Lachner-Sandoval* (1898), recording the same fact, pointed out that Gram staining makes small round Gram-positive bodies visible within the Gram-negative "detritus," which sometimes also may contain some pale shadows of former threads. Another observation, which the author was "unable to explain," because he, too, was not acquainted with the earlier findings concerning the upgrowth of new cells from such "granular detritus," i. e., from the symplasm, was very correctly described by him (l. c., p. 41) as follows:

Bei ganz jungen Individuen sieht man vielfach neben einem Faden oder auf dem Ende eines solchen . . . eine wolkenförmige Masse, die aus winzig kleinen, lichtbrechenden Körnchen besteht.

It will suffice to compare this description with one of our photographs, reproduced as figure 267 on Plate XXI (from *Löhnis* and *Smith*, 1916 *a*, original fig. 28) showing a young thread of our "yellow bacillus No. 41," developing from the symplastic stage, to understand at once the meaning of *Lachner's* "unexplainable" observation.

Some drawings made by *Niessen* (1898) of his diphtheroid "Syphilis-Bacillus," which were reproduced as figure 217 on Plate XVIII (from original fig. 13), should be compared with those of *Morck* and of *Lutz* given above. However, *Niessen's* contributions, as well as those made by *Münden*, are greatly impaired by the fact that the actual observations, discussed therein, are enshrouded by many fantastic ideas and unfounded hypotheses upon "cytoblast," "chthonoblast," the transformation of bacteria into crystals, etc., which have necessarily created a very suspicious attitude among the readers of these papers. But when we free the findings recorded therein, from these accessories, it becomes obvious that *Münden* has also seen the bacterial symplasm in its amoeboid and in its encysted forms, as well as the transformation of these hyalin masses into regenerative bodies of various shape, which ultimately reproduce the normal bacteria.

Very meritorious investigations upon the symplastic stage of bacterial life have been made by *W. Winkler* (1899); and it is hardly to be doubted that they would have attracted much more attention if they had not been discussed rather summarily in one short paper, to which merely drawings were added, which can not convey an adequate idea of what the author found and of what is really to be seen in such experiments. Some of them are reproduced as figure 212 on Plate XVII. In liquid as well as on solid substrates, in mixed and in pure cultures, *W. Winkler* always met with smaller and larger clumps of finely granulated or homogeneous plasma, sometimes inclosed within a solid membrane, in other cases naked and showing amoeboid movements like a plasmodium. Often these clumps assumed a "brain-like" structure, and a small central body ("Mittelpunktkörperchen") became visible within each lobe. One of our photographs, reproduced as figure 231 on Plate XVIII (from *Löhnis* and *Smith*, 1916 *a*, original fig. 12), may serve as an illustration. The transformation of these plasmatic masses into bacteria was directly observed under the microscope and (l. c., p. 576) described as follows:

Die dem Rande zunächst liegenden Granula ordneten sich in Reihen; die einzelnen Körner umgaben sich mit Plasma, rückten auseinander, schwollen an, streckten sich und wurden nach und nach zu Bakterien.

Two of our photographs, reproduced as figures 215 and 216 on Plate XVIII (from *Löhnis* and *Smith*, 1916 *a*, original fig. 32: *Streptoc. lactis*, and 1916 *b*, original fig. 56: *Microc. candicans*) may be compared in this respect.

Sometimes the first cells formed showed very irregular outlines; they were triangular, spindle-shaped, oval, cubic, or more or less irregularly curved. Already in 1880 *Neelsen* has pictured such an occurrence in the drawing reproduced as figure 85 on Plate S (from original fig. 10 on Pl. XI).

Clumps of symplasm of different size were frequently seen by *Winkler* in colonies, especially in those imbedded within the substrate, and here the symplasm was often inclined to send out thread-like protrusions, which the author called "filidia." These filidia may produce more or less normal bacteria, either by contraction or by segmentation, as shown in the right part of figure 212 on Plate XVII (reproduced from *W. Winkler's* original fig. 41), or by furnishing the material for their formation within the more or less solid membrane of the filidium, as illustrated by the two sketches in the upper center of figure 212 (reproduced from original figs. 34 and 35). Sometimes large round bodies, called "macrospores," were seen to grow in the symplasm, or within broad filidia, which acted as "sporangia"; the drawings in the lower left part and in the center of figure 212 (reproduced from original figs. 48 and 50) picture these two possibilities. It is beyond doubt that these "macrospores" of *W. Winkler* are identical with our large round regenerative bodies, whose frequent upgrowth from the symplasm will have to be discussed later.

As far as I know, only one author, *Růžička* (1903), has paid attention to and has continued *Winkler's* work. Unfortunately, he restricted his observations to the study of mixed infusions and buried his data in a paper "Ueber die biologische Bedeutung der färbbaren Körnchen des Bakterieninhaltes." He followed continuously the dissolution of the bacteria cells and their reconstruction from the plasmatic masses, which he calls "zoogloea," and concludes:

Es kann als gesichert gelten, dass die Zoogloea ein Syncytium darstellt, in welchem die beiden Komponenten, die geformten Elemente und das strukturlose Plasma die Fähigkeit besitzen, in einander überzugehen.

But there still remain some more recent observations, all made quite independently, which also represent important contributions to our subject.

When N. K. *Schultz* (1901 *a*) made her investigations upon the longevity of the gonidia of *B. pestis* and their participation in the life cycle of this organism, she noticed that in old cultures minute granules were present, imbedded in weakly staining flakes, which after being transferred to fresh substrates, first produced agglomerations of globular bodies, which soon after grew up to normal rods; but 14 days later the pale flakes with their minute granules appeared again and replaced the vegetative cells. The figs. 218–221, reproduced on Plate XVIII (from original figs. VII–IX and XII), illustrate these changes very clearly. However, the Russian bacteriologist was not aware that she was facing the symplastic stage of the plague bacillus. The flakes inclosing the granules were thought to be "le précipité floconneux du bouillon," and of course, especially in the several years old cultures, such an occurrence had been quite probable. But the very pronounced similarity between the old and the new flakes proves that this was not the case. The artist (*Ivanoff*), who made the pictures and merely copied what he saw, without being blinded by any prejudice, showed very clearly that the new flake (fig. 221) is formed by the residues of the agglutinated cells, which had become unstainable. Moreover, it will suffice to compare these pictures with others reproduced on our plates to feel convinced that also in this case it was the symplasm, not some dead precipitate, which made such luxuriant upgrowth possible.

The actinomyces-like buds which *Lignières* and *Spitz* (1902) found growing out of the hyalin homogeneous mass, which formed the grains in the pus of cases of actinobacillosis, are very similar to those of *Metchnikoff's Pasteuria ramosa*, as may be seen from the drawings of the first-named authors, reproduced as figure 213 on Plate XVII. It is true that *Metchnikoff* did not pay any special attention to the fact that the characteristic clubs of his Pasteuria were produced by flakes of hyaline symplasm, but a photograph made by *Roux*, which was added to *Metchnikoff's* (1888 *b*) drawings, and which is reproduced as figure 222 on Plate XVIII, proves this point.

A bacillus, evidently related to *B. pneumoniae*, if not identical with it, was studied by *Jehle* (1902) with the result that hardly any normal cells were seen in 5–8 days' old cultures, but numerous crumbly pale masses and flakes, which after being transferred to new substrates promptly reproduced polymorphous cells.

With regard to leprosy *Pernet* (1902) reached the conclusion that the "gloeal masses," which he, like G. A. *Hansen* (1880–1882), *Babes* (1883), and *Lutz* (1886), found within the tissue cells, are not products of degeneration, but "a phase in the parasite's life history, a resting stage, during which it prepares for further proliferation," and he pointed out that clinical observations are in good agreement with this view.

Fuhrmann's (1906–1908) results with *Pseudomonas cerevisiae* are very similar to those recorded by *Schultz* with *B. pestis*. Here again the "detritus" containing minute granules, showed itself to be able to reproduce new vegetative cells after long periods of rest. A good photograph, published in the second paper (1908, original fig. 5 on Pl. I) and reproduced as figure 238 on Plate XIX, exhibits the typical appearance of the symplasm with its regenerative units, regenerative bodies and new rods.

Some very important contributions to our subject have been made by *Rosenbach* (1909), when he studied his polymorphous Erysipelothrix (*Bac. erysipeloides*). The four photographs reproduced as figures 239–242 on Plate XIX (from original figs. XIV, 6; XII, 2; XIII, 2 and XII, 1) are of special interest. The rods, whose normal appearance was shown in figures 26 and 27 on Plate III, agglomerate and enter into granular dissolution (fig. 239); the end products are visible in figure 240. Occasionally these granular clumps may reproduce fine threads, as shown in figure 241, or even a distinctly mycelial growth may spring forth from them, like that in Figure 29 on Plate III. Sometimes, however, the dissolution of the rods ends with the formation of completely homogeneous masses, which may surround themselves with rather solid membranes, thus forming large globules, as shown in 270-fold magnification in figure 242. This encystment of the symplasm is of great interest when compared with those old reports,

made by *Letzerich* and other early bacteriologists upon the production of large cysts by typical bacteria closely resembling the cysts of certain Myxobacteriaceae.

The symplastic stage of the tubercle bacillus, so well studied by *Klebs* (1883) and by *Malassez* and *Vignal* (1883–84), but so flatly rejected by R. *Koch* (1884), was once more discovered and fairly thoroughly investigated by *Maher* (1910–1913). He became aware that it is especially due to the ability of this nonacid-fast "matrix" to reproduce many different forms of various staining reactions why old cultures of tubercle bacilli are so much inclined to furnish cells of very variable size, shape, and pigmentation. According to our own experience the following statement, made in *Maher's* second paper, allows a wide generalization:

> From this matrix it is possible to grow coccal and bacillary forms that vary in morphology, in acid resistance, and in chromogenic power, according to the variance in the age and vegetative energy of the tubercle bacilli that composed the matrix, and according to the variance in the technique to which the matrix is subjected.

At least partially correct were also the findings of *Herzog* (1913) concerning the slimy dissolution of gonococci, or of whole colonies of these organisms, into a yellowish, transparent mass, which at first still contained some minute globular bodies, later, however, became either entirely homogeneous—in this case its was declared to be dead—or transformed itself into oval or globular "giant forms."

That *Meirowsky* (1914 *b*) in his investigations upon the development of the bacteria frequently met with the symplastic stage of various bacilli, spirilla, and spirochaets is clearly demonstrated by a number of the pictures accompanying his paper. For instance, the sketches of *Spirillum rubrum*, reproduced as figure 86 on Plate S (from figs. 4 and 5 on Pl. V *b*), and some of the illustrations of "Doldenbildung," shown on Plate XIV, leave no doubt upon this fact. But *Meirowsky* himself thought these "umbels" were closely connected with the "bud formation," caused by the gonidia leaving the cells, and he stated at first (p. 9) explicitly:

> Die Dolden sitzen stets am Ende des Bazillus und stellen eine feine wolkige Masse dar, die aus zahlreichen sehr kleinen, stark lichtbrechenden Körperchen besteht.

Later (p. 16), however, he admitted that the "umbels," made up of small granules embedded in a zoogloea-like matrix, were often found without being attached to a rod, and that he also saw all intermediate stages between these masses and new vegetative cells. The size of such agglomerations exceeds that of a bacillus or of a spirillum frequently so manifold, that it would be quite inconceivable how they might develop from one single cell; the opposite process is, no doubt, much more probable.

Some very characteristic photographs, published by *Almquist* (1916–1917), demonstrating the development of new cells from what he calls bacterial "plasmodia," have been reproduced as figures 243–247 on Plate XIX (from original figs. 12 and 22, 1916, and Nos. 5, 6, and 12, 1917). Figure 243 presents the upgrowth of *B. typhi;* besides fairly normal rods, large yeast-like forms and peculiarly slimy threads are visible, "in statu nascendi." Figure 244 shows the round regenerative bodies of *V. cholerae* being formed within a flake of symplasm. This picture should be compared with figure 238 (symplasm of *Pseudomonas cerevisiae Fuhrmann*). Figure 245 was made from a single cell culture of *B. diphtheriae;* together with figure 246, *B. acidi propionici c*, it exemplifies the possibility of very irregular forms consolidating themselves out of large and small flakes of symplasm. Figure 247 pictures the symplasm of *Almquist's Bact. antityphosum* (cf. p. 147); it may be compared with figure 216 on Plate XVIII, presenting *Micr. candicans* in the same phase of its life cycle, and also with figure 223 on the same plate, which is a reproduction of a picture made by *Kellerman* and *Scales* (1916) of the first beginning of new growth of *B. coli* from the symplasm. Another photograph of the same authors, reproduced as figure 224 on Plate XVIII, illustrates once more the concentration of the pale granular mass first into an unsharp slimy thread, like those photographed by *Almquist* of *B. typhi* (fig. 243), and the progressive consolidation of parts of this thread into normal, deeply staining rods. Two other coli pictures, made by *Kellerman* and *Scales* (1916) and reproduced as figures 44 and 45 on Plate IV as an illustration of the pleomorphism of this

species, will now also be better understood as to their true meaning. They show clumps of the large yeast-like cells, so frequently originating in and from the symplasm, and another example of such broad threads, to be compared with *W. Winkler's* "filidia."

The summary of the results of our own preliminary studies upon the symplastic stage of representatives of various groups of bacteria has been given on page 166. It may be added here that by some special experiments (*Löhnis* and *Smith*, 1916, *a*, p. 679) the fact has been definitely established that not only in old, but also in very young, cultures the formation of symplasm may take place in accordance with the tendency of the bacteria to live alternately in an organized and in an amorphous stage. Some of our photographs, illustrating the various steps leading from cells to symplasm and back to cells of the same or of a different type, have been reproduced as figures 225–233 on Plate XVIII, figures 250–261 on Plate XX and figures 262–267 on Plate XXI. As a detailed discussion of these pictures will better find its place on the following pages, it may suffice to mention here that figures 225-231 on Plate XVIII and figures 250-258 on Plate XX were all made from Azotobacter. Figure 232 (Pl. XVIII) and figures 259–263 (Pls. XX–XXI) illustrate different phases in the life cycle of *B. fluorescens*. A flake of symplasm of *B. subtilis* is shown in figure 233 (Pl. XVIII) for comparison with figure 230. The upgrowth of *Sarcina flava* is demonstrated by figure 264 (Pl. XXI). Figure 266 shows peculiarly pointed cells of *B. malabarensis*, whose large gonidia break out before melting together to the symplasm. A thread of the "yellow bacillus No. 41" growing up from the symplasm is visible in figure 267.

It needs hardly to be emphasized that these photographs furnish fairly accurate illustrations to several of the early descriptions, mentioned above, or somewhat superior counterparts to the rather primitive drawings, made by the earlier authors. It should be pointed out, however, especially for those readers who have not yet seen such preparates under the microscope, that even the best photographs can only convey a very incomplete impression of the actual appearance of this type of growth. Large flakes or clumps of symplasm, which make the most interesting object under the microscope, can not be photographed at all. And even so many parts of the smaller agglomerations are necessarily out of focus, that the flat photographic picture is always very inferior to the bright and plastic appearance of the symplasm under the microscope.

But in one direction these photographs will hardly leave any doubt, viz., that a thorough study of this particular phase of the life cycles of the bacteria will supply us with very valuable and much needed information upon the occurrence of different cell forms, the real significance of so-called involution forms, the appearance and disappearance of variations and mutations, and many other data, which could not be obtained with the customary methods of investigation.

Cultures showing "autolysis" or "granular decomposition" of their cells are usually discarded as speedily as, or even more lightly than those producing "involution forms," much to the disadvantage of bacteriological science. From the descriptions furnished by authors like *Ermengem* (1885, p. 20), *E. Klein* (1885, p. 111), *Gamaleia* (1900 pp. 27, 154), *Kruse* (1910, p. 20), *Rettger*, *Berman* and *Sturges* (1916), and many others, it may be safely concluded that more thorough tests would have demonstrated, that also in these cases "degeneration" would have been supplanted by "regeneration," as soon as suitable conditions for the revival of cell life had been established. It is, of course, self evident that permanently adverse conditions must end all life, but "autolysis" of the bacteria is by no means equivalent to death; in fact, it enables the living matter to readjust itself and to reenter cell life in a better adapted modification. Every experienced bacteriologist knows that careful testing will bring many cultures back to good growth, which on superficial examination would be declared dead. That "autolysis" may be followed by renewed development has been observed, e. g., very clearly by *Malfitano* (1900) in his experiments upon "La bacteriolyse de la bactéridie charbonneuse" in full agreement with those made by *Fokker*, which were discussed on p. 171. A few hours after the bacilli had been transferred into distilled water only an "amas de débris informes" remained, but the author adds:

> Le phénomène est très net, bien que, dans ces conditions de nouvelles bactéridies puissent se former.

Kruse (1910 p. 21) also says:

Unter Umständen tritt in denselben Mitteln (i. e. in old cultures, serum, etc.) Bakteriolyse und Wachstum neben oder nacheinander auf, indem nämlich die durch Selbstverdauung schon zugrunde gegangenen Bakterien den übrig gebliebenen den Nährboden . . . verbessern . . . oder . . . im Serum die Alexine neutralisieren.

A more complete knowledge of the facts recorded by the earlier authors would probably have replaced the hypothesis in the last part of this statement by a more correct reference to the bacterial symplasm.

That the bacteria are to be frequently found in their amorphous stage in vivo as in vitro has been indicated by the quotations taken from the publications of *Osler* and *Schäfer* (1873), *Letzerich* (1873–1876), *Weigert* (1875), *Klebs* (1878–1887), *R. Koch* (1878), *G. A. Hansen* (1880–1882), *Albrecht* (1881), *Fokker* (1881–1882), *Babes* (1883), *Malassez* and *Vignal* (1883–1884), *Cornil* and *Alvarez* (1885), *Eberth* (1885), *Amrusch* (1886), *Lutz* (1886), *Nocard* (1889), *Crookshank* (1896), *Lachner-Sandoval* (1898), *Lignières* and *Spitz* (1902), and *Pernet* (1902). More recently renewed attention was given to this point. A photograph made by *E. de Negri* (1916) of the amorphous masses found in granulom tissue, caused by a Corynebacterium, has been reproduced as figure 237 on Plate XVIII. What *Mallory* and *Medlar* (1916) described and pictured as "clumps of bacilli," taken from the tonsils in cases of scarlet fever, show very clearly their symplastic status, when we compare the photograph reproduced as figure 248 on Plate XIX (from original fig. 23 on Pl. XX), for instance, with figures 216, 246, 247 and 254 on Plates XVIII–XX. The same holds true in regard to a photograph made by *Mellon* (1917, original fig 5, Pl. 2) of "a colony of diphtheroid bacilli lying in the interstitial tissue of the lung," which was reproduced as figure 249 on Plate XIX. In cases of poliomyelitis, *Rosenow, Towne* and *Wheeler* (1916) found often in tonsillar abscesses "a peculiar gelatinous opalescent material from which the peculiar Streptococcus was isolated in large numbers." And when *Wade* (1918) studied an unclassified chronic Philippine ulcer, he obtained results which are in complete agreement with the numerous findings mentioned above, although according to the author's own judgment his "hypothesis departs radically from orthodox views." He says:

"Essentially it appears as if the differentiated demonstrable parasitic element in a mycotic lesion may give rise to a derivative substance, morphologically not differentiated and perhaps even quite amorphous, that, unlike the known toxins, soluble or insoluble, is by itself more or less viable and may be capable, to a certain extent at least and under certain conditions, of persisting as such and even of increasing or growing."

This "substance or body" was named by *Wade* "cryptoplasm," while for the large round bodies, which were again seen to develop from it, the term "cryptococcus" was introduced.

It is to be expected with certainty that more confirmative results will be secured as soon as the hyalin and amyloid substances of the body will be made the object of new studies along these lines. Descriptions published by *Lubarsch* (1903) leave no doubt that appearance and staining reactions are very much alike in both cases, and though he does not refer to a participation of microorganisms in the formation of these substances, this has been done already in 1878 by *Klebs* and in 1885 by *Ziegler*, who pointed out (1885, p. 285) that epithelial cells, when attacked by bacteria, swell up and liquefy or degenerate into homogeneous lumps or granular detritus. To what degree the cells of the host on the one side, and those of the parasite on the other, are to be made responsible for the outcome apparently nobody has ever tried to decide. But that the living plasmatic substances of the higher organisms, especially those building up the animal tissue, are equally able to enter and to pass through such a "symplastic" stage as the bacteria do, has been pointed out by *Robin* about half a century ago, according to *Béchamp* (1883, p. 543), in the following statements:

En anatomie génerale on appelle blastème ou cytoblastème des espèces de substances amorphes liquides ou demiliquides, soit épanchées entre les éléments anatomiques préexistantes dans un tissu ou à sa surface, soit interposées entre des éléments qui naissent à leur dépens au fur et à mesure de leur production au sein ou à la surface d'un tissu.

Dans le blastème prennent ou peuvent prendre naissance des éléments anatomiques, normaux ou morbides (granulations moléculaires, fibres, tubes, cellules, etc.).

Le blastème est une matière complètement homogène, amorphe, sans structure.

And quite recently *Burrows* and *Neymann* (1917) reported upon their "Studies on the Metabolism of Cells in vitro" as follows:

Growth associated with mitotic cell division is seen only in (tissue) cells which have become passively placed at the interspace between certain insoluble substances and the medium. These substances are liberated from the cells when they are removed from their normal habitat to an oxygen containing plasma or salt solution. The substances are almost transparent, their refraction is not very different from that of the original medium and they accumulate at the surface of the medium to form a membrane. They are liberated in large amounts from a tissue fragment rich in cells.

A cell brought in contact with the surface of this transparent substance adheres to it and flattens over its surface. Such a cell grows and divides by mitosis when oxygen is present and the waste products remain below a certain concentration.

A single isolated cell when placed in a drop of fresh plasma does not grow and divide.

It is hardly to be doubted that a close study of the symplastic stage of bacterial life will yield information of considerable value for general biology. The formation of new cells directly out of the amorphous plasma can perhaps in no case be better observed than with the bacteria, although lower fungi, as well as protozoa, may also furnish excellent objects for such investigations, as had been noticed by *Pineau* and *Perty* a long time ago, according to their studies discussed on pages 167–168.

When referring to *Thaxter's* Myxobacteriaceae (on p. 174) it has been pointed out that the more complete knowledge of the life cycles of the bacteria undoubtedly establishes much closer connections between these two groups of organisms, as well as with the Myxomycetes. *W. Winkler* (1889) concluded from his observations that the bacteria are related to Myxomycetes as well as to Amoebae and that the Myxobacteria are true bacteria. In 1866, *Woronin* placed the root-nodule organism (*B. radicicola*) in the neighborhood of Plasmodiophora, as did later *Kny* (1879) and *Prillieux* (1879). *Schroeter* (1886, p. 134) and *Atkinson* (1893) class it among the Myxomycetes; *Zukal* (1897), *Stefan* (1906), *Jörgensen* (1911), and *Pinoy* (1913) emphasized its relationship to the Myxobacteriaceae. It is not to be disputed that the formation of spores and cysts by the Myxobacteria, as it has been described in the publications of *Thaxter* (1892–1904), *Zukal* (1897), *Baur* (1905), *Quehl* (1906), *Kruyff* (1908), *Vahle* (1909), *Jahn* (1909–1911), and *A. L. Smith* (1913), at the first moment seems to have very little in common with the general behavior of the bacteria. But it must never be overlooked that the experimental conditions under which the bacteria are nearly always kept and studied also do not allow the Myxobacteria to develop in their characteristic form, as has been shown, for instance, by *Quehl* and *Vahle*. The small *Bac. helixoides* ($0.6 \times 2–4\mu$,) isolated by *Muto* (1904) from saliva, which grew on the plate in colonies made up of rods at the edge and oval forms in the center and sent out slimy protrusions creeping forward like snails, undoubtedly has been a maltreated Myxobacterium. *Jahn* was certainly right when he wrote:

Die den Myxobakterien eigentümliche Form der Coloniebildung ist auch bei den Bakterien nicht so ungewöhnlich, und sie würde auch den Bakteriologen noch vertrauter sein, wenn sie mehr gewohnt wären, die Bakterien unter ihren natürlichen Lebensbedingungen zu beobachten.

A bacillus isolated by him showed in a nutrient solution a behavior very similar to that of Myxobacteria:

Verschlechtern sich die Existenzbedingungen, so vereinigen sich die Bacillen zu einem dichten Haufen und tanzen lebhaft wie ein Mückenschwarm durcheinander. Dann kommen sie allmählich zur Ruhe, sondern Schleim ab und bilden eine characteristische Colonie aus rundlichen, verkürzten Individuen.

When studying the "zoogloea" stage of the bacteria in 1877 *R. Koch* also reported (p. 415) to have seen the cells within the zoogloea agglomerate into groups of 10–12 individuals and to enter spore formation. *Zikes* (1916) observed on dry gelatin a growth of bacteria, as well as of yeasts, which was microscopically as well as macroscopically similar to that of certain myxobacteria.

That the spore formation of the Myxobacteriaceae is fundamentally identical with the production of arthrospores and microcysts of the bacteria has been discussed on page 123. The same holds true in regard to the agglomeration of the vegetative cells and their slime production preceding the encysted stage of the myxobacteria, and the symplastic stage of the bacteria. As figure 87 on Plate S a drawing made by *Baur* (1905) of *Myxococcus ruber* in

the beginning of fructification has been reproduced (from original fig. 3 on p. 113). It should be compared with one of *Rosenbach's* photographs, reproduced as figure 239 on Plate XIX, showing *B. erysipeloides* before entering the symplastic stage. The more or less complete dissolution of the vegetative, as well as of the reproductive, cells of the bacteria forming the symplasm obviously constitutes the most pronounced difference although perhaps a similar behavior may still be discovered among myxobacteria, as well.

The encystment of these agglomerations is also by no means absent among the bacteria. The cyst of Polyangium, drawn by *Zukal* (1897, original fig. 8) and reproduced as figure 88 on Plate S, makes a counterpart to some of the old sketches of bacteria found in cases of diphtheria by *Letzerich* (1876, reproduced as figs. 68 and 80 on Pls. P and R) and of a leprosy zoogloea, published by *G. A. Hansen* (1880, original fig. 10). The "macroplasts" of *Bact. rubescens*, studied by *Lankester* (1876) and reproduced as figure 209 on Plate XVI, the "zoogloea" form of Nitrosomonas, as photographed by *Winogradsky* (1892) and reproduced as figure 270 on Plate XXI, the Asococcus of *Billroth* (1874) and *F. Cohn* (1875), the Clathrocystis of *Cohn* (1875), the Ascobacteria of *Van Tieghem* (1880), the *Micrococcus botryogenus* of *Rabe* (1886), the Amoebobacter and Thiocystis of *Winogradsky* (1888, pp. 60–78), the Ascobacterium of *Babes* (1895), the Ascobacillus of *Moreno* (1901), as well as the "bacteriocysts" of *Müller-Thurgau* (1908), which are to be discussed on the following pages, indicate all very clearly that large encysted agglomerations of cells are not at all uncommon among the bacteria. Even the homogeneous symplasm may encapsulate itself, as was shown by *Rosenbach* (1909) in the photograph reproduced as figure 242 on Plate XIX. That it will mostly depend on the environmental conditions whether or not such macrocysts will be formed by the bacteria, may be safely assumed, though hardly any experimental results are available at present in this direction. *Pinoy* (1913) pointed out that symbiotic (or antagonistic?) effects may act as stimulants in this direction; and, indeed, we should never forget that our pure cultures on standardized media will often fail to exhibit the characters shown by the mixed microflora under natural conditions.

That the bacterial symplasm is able to reproduce either round regenerative bodies or directly vegetative cells is another parallelism to the behavior of the myxobacteria, which pass their resting stage either as spores or as vegetative cells. But with the bacteria both modes of regeneration occur apparently with every species, while in the latter case a more distinct differentiation has taken place.

The occurrence of bacterial plasmodia, showing amoeboid movements, indicates relations existing between bacteria and Myxomycetes, as was pointed out by *W. Winkler* (1899). *De Bary* (1884, p. 477) thought the Myxomycetes should be separated from the fungi and should be called, together with the Acrasiae, Mycetozoa. However, as *Henneberg* (1904) has demonstrated more recently, amoeboid stages may be also found with true fungi (yeasts); on the other hand, amoeboid movements of the bacterial symplasm do not seem to be a general character, and more thorough studies very probably will reveal many analoga to the bacterial symplastic stage among protozoa, as well as among fungi and algae. Therefore the relations existing between bacteria and protozoa should not be too much enhanced on account of this one point.

(b) FORMATION AND APPEARANCE OF THE SYMPLASM.

According to the observations made by *Lankester* (1876), *W. Winkler* (1899), *Rosenbach* (1909), and *Löhnis* and *Smith* (1916 *a* and *b*) the formation of the symplasm always takes place in two phases: First, the bacteria agglomerate to smaller or larger clumps; second, the cells dissolve more or less completely to a crumbly or slimy mass, assuming the shape of flakes, irregular clumps, or regular spheroid bodies, and being sometimes endowed with amoeboid motility.

Apparently all species of the bacteria and all kinds of vegetative cells, as well as of reproductive organs, are able to enter the symplastic stage. It occurs both in old and in young cultures, dependent on internal as well as on external conditions.

A so-called pseudo-agglutination has been frequently noticed in connection with agglutination tests; it has been discussed by *Savage* (1901), *Escherich* and *Pfaundler* (1903, p. 341), *Hiss* and *Zinsser* (1914, p. 231), and others. *Hewlett* (1902, p. 143) found that "agglutinins" were present in old broth cultures of typhoid bacilli; filtrates obtained therefrom powerfully agglutinated the bacilli in fresh broth cultures. *Nocht* and *Mayer* (1907, pp. 18, 33) report that spirochaets often agglomerate when kept for a longer time at low temperature or in serum, that the agglomerated cells occasionally fuse together in the center, and that sometimes "desagglomeration" was observed. That similar clumps of spirochaets may be also found in the tissue is indicated by a photograph made by *Flexner* (1907) of "colony-like" masses present in the skin of a macerated syphilitic foetus. *McFarland* (1916, p. 721) says referring to this picture: "The dense aggregation of organisms may indicate agglutination." There is no doubt, however, that the agglomeration preceding the formation of the symplasm is essentially different from the typical agglutination, though both processes present a very similar appearance. Agglutination is, according to the careful review published by *Köhler* (1902), prominently a physico-chemical reaction, whereas the active gathering of the cells, when entering the symplastic stage, makes it quite evident that in the first place a biological cause is active in this case, though external, physical as well as chemical, factors will naturally also exert their influences, hastening or retarding the agglomeration of the cells.

The dissolution of the united cells leaves either the empty cell walls as "shadows," but still clearly visible, in the field, or they, too, are disintegrated and participate in the formation of a more or less homogeneous symplasm, which often becomes entirely amorphous, hyalin, and highly refractive. Our photographs reproduced as figures 225–231 on Plate XVIII (from *Löhnis* and *Smith*, 1916 *a* and *b*) illustrate these various modes of formation of the symplasm, which may all occur with the same species, as shown here with *B. azotobacter*. That all types of vegetative cells, as well as of reproductive organs, are able to enter the symplastic stage is also demonstrated by these photographs.

Like the structure, the staining reaction of the symplasm can also show wide variations. In such cases where darkly staining membranes, especially those of regenerative bodies, participate in the process generally deeply staining flaky masses are produced, whereas the voluminous clumps, resulting especially from dissolved endospores or gonidia or from the agglomerated contents of large vegetative cells, are usually entirely unstainable by aqueous dyes. Frequently of course, large masses of symplasm are made up by both deeply staining and unstainable parts. *W. Winkler* (1899) reported to have directly observed the transformation of crumbly dark flakes into voluminous "plasmodia." Thus far I have not seen such changes; but the presence of very thick clusters of the peculiar bright slimy masses in old cultures rich in symplasm makes it, indeed, quite probable that special structural alterations may take place, which remain to be studied. *Letzerich* (1876), too, has reported that he observed directly a growth of bacterial "plasmodia" as such; the inner circle inserted within the large irregular symplasm in the lower left corner of the drawing reproduced as figure 80 on Plate R was explained by the author as indicating the original size from which the upgrowth started. It is impossible to decide at present whether or not this old report is to be accepted as correct.

The variations in the staining qualities of the symplasms make it easily to be understood why, for instance, the tuberculosis "zoogloea" was found by *Malassez* and *Vignal* (1884) to be not acid-fast and either not at all or with difficulty to be stained with aqueous dyes, while *Amrusch* (1886) recorded a slight acid-resistance. *Metchnikoff* (1888 *a*) saw the slimy amorphous masses assume a yellow color, when they were treated like the tubercle bacilli; and *Maher* (1910–1913) found again his tubercle "matrix" to be either not or slightly acid-fast. According to *Lutz* (1886) the "gloeal masses" of *B. leprae* are stainable with common aniline dyes, and turn bluish-red when treated with Gram's method, while they were seen by *Pernet* (1902) to vary in their staining qualities. Analogous results concerning the "plasmodia" of *B. radicicola* have been recorded by *Hiltner* (1898), and by *Bastian* (1905, p. 186) with his mixed cultures.

Iodine stains the symplasm either yellow or brown, like the hyalin and amyloid substances in the animal tissue, but this reaction may again vary, as has been shown by *Morck* (1891) with

B. radicicola. *Letzerich* (1874) saw sometimes, but not regularly, a blue color develop in his diphtheria "Plasmaballen" when they were treated with iodine and sulphuric acid.

Amoeboid movements of bacterial symplasms have been seen by *Letzerich* (1876), *Dowdeswell* (1889), *W. Winkler* (1899), and *Münden* (1907). *Dowdeswell's* observations, which were made with *V. cholerae*, have been refuted by *Friedrich* (1892), who asserts that they can not be accepted as correct. The German author admits, however (p. 104), that he also saw the bacilli dissolve into irregular flakes of plasma ("unregelmässige Plasmafetzen"). But that he did not see a new growth of bacilli arising from these flakes was very probably due to faulty experimenting. Internal, oscillating or gyrating movements have been noticed by *Perty* (1852), *Amrusch* (1886), and by *Frank* (1890). I have also seen this kind of movement in hyalin symplasm, whereas I have had no opportunity thus far to confirm the findings concerning amoeboid motility.

That the voluminous agglomerations of symplasm are endowed with a comparatively high resistance against the solving action of acids, alkali and hot water is a priori very probable. The prominent rôle which they have played in *Bastian's* experiments on "abiogenesis" and "heterogenesis" shows that they readily withstand long continued heating. *Metchnikoff* (1888 *a*) discovered that the symplasm of *B. tuberculosis* is very resistant against acid and alcohol. *W. Winkler* (1899) found out that by adding a 4–10 per cent solution of caustic alkali the symplastic masses present in thick bacterial growth become clearly visible, because they are less easily dissolved than the bacteria. And when I encountered for the first time what later turned out to be the symplasm of *B. azotobacter*, I also tried in vain to dissolve these doubtful clumps by treating them thoroughly with acid and with alkali. That they are sometimes hard to fix on the slide, by heating as well as by alcohol, has been mentioned above. This behavior, together with their heat resistance, will be considered in Chapter V, on account of their liability to cause faulty results.

That the increased resistance also protects the life within the symplasm to a considerable degree has been demonstrated by *Fuhrmann* (1908), who discovered that what he called the "detritus" of *Pseudomonas cerevisiae* remained alive for several months in a 10 per cent NaCl solution, wherein a young agar culture of the bacilli died within a very short time. If the symplasm encysts itself, as was observed by *Rosenbach* (1909), its resistance will evidently be still more increased, and at the same time its function as resting stage becomes quite obvious.

That this melting together of numerous cells and the ensuing thorough mixing of their ingredients are of great importance in regard to a better adaptation of the living substance to the environmental condition is especially clearly indicated by the very pronounced tendency of the liberated gonidia to enter first the symplastic stage, before reproducing new cells. As was discussed in the foregoing chapter, the gonidia grow up to new cells very readily while still connected with the parent cell, or if they have otherwise access to genuine plasma, like that in dead or dying cells of fungi and algae. But in other cases free gonidia have been rarely found to be inclined to act promptly as normal reproductive organs, when kept under ordinary laboratory conditions, whose rather unnatural character is beyond dispute. Dissolution of the gonidia has been mentioned in the early publications of *Perty* (1852) and of *Billroth* (1874), and the same fact has induced many other investigators to believe that also in this case dissolution means death, and no further investigation was thought to be necessary. *F. Cohn* (1870) as well as *Zopf* (1879) have noticed, however, that the microgonidia produced by Crenothrix, instead of germinating to new threads, as the macrogonidia always did, first agglomerated to a "zoogloea," which after a period of rest gave new vegetative growth. *Ewart* (1878 *a*) recorded analagous results with the "spores" (gonidia) of "*B. termo*" (*B. fluorescens*); only after having formed the "zoogloea" they were able to reproduce rods. And it is not improbable that the reason why *R. Koch* (1877), after having made his interesting first photograph of the "lateral spores" (gonidia and regenerative bodies) of *B. fluorescens*, which was reproduced as figure 109 on Plate X and discussed on page 92, never returned to this subject, has again been this mistaken dissolution of the small round bodies. Anthrax gonidia displayed the same

deceptive behavior, when first studied by *Fokker* (1881–1882), and also their rôle, as well as that of the gonidia of other parasitic bacteria, therefore, has often been overlooked.

Very conspicuous is the formation of symplasm when large gonidangia, containing numerous gonidia, break up, forming a small flake or clump of hyalin substance. *Dowdeswell* (1889–1890) has been probably the first who did not follow the generally observed easy rule to discard quickly all such "dead involution forms." He studied carefully the flocculent "débris," formed by the gonidangia of *V. cholerae*, and saw new curved bacilli develop from the minute granules inclosed within the plasma flakes, which also sometimes exhibited amoeboid movements. *Mafucci* (1892) obtained similar results with the club-shaped gonidangia of *B. tuberculosis*, though he only assumed that the deeply staining "granules" within the granular masses might act as "spores," without being in the possession of an accurate experimental basis, on which to found his belief. *Meyerhof* (1898), who worked with diphtheria bacilli, was more radical when he reported that the clubs within 8 days disintegrated—

in krümelige Produkte, die als abgestorben angesehen werden mussten.

No explanation was given why the author felt compelled to draw this conclusion without first studying the subject more closely. The latter was done by *Fuhrmann* (1906–1908), who was careful enough not to discard lightly what he also considered to be merely "detritus" of the club-shaped gonidangia of *Pseudomonas cerevisiae* and related organisms. Therefore, he secured the characteristic upgrowth from it, as was shown in the photograph reproduced as figure 238 on Plate XIX. Similar results have been recorded by *Růžička* (1908) with *B. anthracis* and by *Herzog* (1913) with *Microc. gonorrhoeae*.

Especially noteworthy is the symplastic stage with the filterable gonidia. Authors who have studied these smallest bodies more thoroughly have always encountered pale, slimy masses of variable staining reaction, wherein the minute granules often showed a comparatively conspicuous upgrowth. The small globular or dumb-bell-shaped cell inclusions, observed by *Bernhardt* (1911) in scarlet fever, were seen to be embedded within the cells in a plasmatic stratum of a peculiar "cloudy" structure, which took the stain sometimes weakly, in other cases, however, quite readily. On the other hand *Hoefer* (1911), who studied the same subject at the same time in the same laboratory, did not see the small bodies found by his colleague, but only homogeneous, hyalin clumps of different outlines, which later contained numerous smallest granules. He is inclined to believe that these formations represent another phase in the development of the cell inclusions, and both descriptions taken together fit indeed exactly the general character of the symplastic stage of the bacteria. Furthermore, the photograph made by *Mallory* and *Medlar* (1916) of the agglomerations of their *B. scarlatinae*, taken from the tonsils, which was reproduced as figure 248 on Plate XIX, also leaves no doubt about its being a typical picture of a clump of symplasm, just beginning to reproduce larger cells. The trachoma bodies were found by *Addario* (1912) to be equally embedded in a homogeneous substance, and the coccoid bodies, isolated by *Noguchi* and *Cohen* (1913) from the trachoma inclusions, again formed clumps of finely granular structure. The "clusters of very minute organisms of quite indeterminable morphology," discovered by *Hort* (1916 *a*) in meningitis filtrate, apparently have been very similar to the small clumps of symplasm, which were found in our cultures of the filterable gonidia of *B. fluorescens*, and of which one is shown in the dark field in figure 234 on Plate XVIII (reproduced from our first preliminary paper, original fig. 42). The filterable organism isolated by *Healy* and *Gott* (1916) from the tissues of cholera hogs is said to occur also "in very small clumps, showing many minute bright points"; the plasmatic mass was once more found to stain either deeply throughout or not at all. A paper by *Foster* (1917) upon the etiology of common colds is accompanied by a photograph (original fig. 3, Pl. 9) showing clearly the symplasm formed by the filterable gonidia just beginning to reproduce small globoid bodies. Very similar pictures from the poliomyelitis germ have been published by *Amoss* (1917, pls. 44 and 46), and that excellent photograph of the symplastic stage of the filterable *Bact. antityphosum* of *Almquist* (1917), reproduced as figure 247 on Plate XIX and discussed on p. 177, deserves to be studied once more in this connection.

(c) REPRODUCTION OF REGENERATIVE BODIES AND OF VEGETATIVE CELLS FROM THE SYMPLASM.

The highly interesting reconstruction of cells from the symplastic stage may proceed, like the formation of the endospores within the cells, along two slightly different lines. Either the agglomeration of the granular material and its consolidation to a new full-sized cell are most conspicuous, or at first one center of reorganization becomes clearly visible, from which the new cell evolves in a comparatively slow development. Undoubtedly the first mode of action is the more striking one, and it has, therefore, prominently attracted the attention of such early investigators as *Pineau*, *Perty*, *Bastian* and *Béchamp*, whose reports and drawings have been quoted and discussed on the foregoing pages (pp. 167–172). But the second possibility has been also admirably described as early as in 1876 by *Lankester*, whose very interesting description and drawings have been reprinted on page 170 and on Plate XVI (fig. 209). *W. Winkler* (1899), too, saw the separate centers of organization surround themselves with plasma and in this way grow up to new cells (see the literal quotation on p. 175).

According to my own observations both types of reproduction may be found with the same species. Stained preparates show invariably as the first step the reappearance of minute deeply staining granules, which are especially conspicuous in the hyalin type of symplasm; we have named them "regenerative units" (*Löhnis* and *Smith*, 1916 *a*, p. 680). When large cells are formed directly, several of these units will gather and surround themselves with the uniting membrane; in other cases one unit increases slowly in size and builds up the new cell. It is quite obvious that these regenerative units are nuclear in character, and the same diversity which is noticeable in the adult bacteria cell (see p. 109) becomes also evident in its embryonic stage. This parallelism extends still further. In those cases where only one deeply stained granule is visible within each new cell, this either stays there as such, or it spreads uniformly throughout its inclosure.

Our photographs reproduced as figures 253–264 on Plates XX and XXI illustrate these different modes of reconstruction, as far as this is possible by such pictures, which are necessarily more or less inferior to the real appearance of the objects under the microscope. Appearance, agglomeration, and upgrowth of the minute regenerative units are well discernible, and a comparison of figures 256 and 262 with most of the others demonstrates clearly how the cells sometimes instead of emerging slowly as separate units from and within the amorphous symplasm are directly and sharply cut out from their matrix, which in this way divides itself, much as certain protozoa do, into "schizonts" which only after separation assume again their typical cell form. As figure 256 demonstrates, new sporulating rods may come into existence as such, although at first of a queer tadpole shape, they display prominently their embryonic endospores, which usually reach their full development together with the newly born cells themselves. Another noteworthy peculiarity is the development of entirely pale bodies, which may multiply as such for a long time, always refusing to take the aqueous stain. They are visible in figures 259, 262, and 263; in the last case the transformation of the deeply stained hairy symplasm into these unstainable bodies is very conspicuous, while it is a little more difficult to discern the pale ovals within the stained cloudy agglomerations of figure 262. All three photographs were made from *B. fluorescens*, but other species exhibit sometimes an analogous behavior. Occasionally a deeply staining granule is visible within an irregular pale cell, or within each segment of a pale sheath of varying length, but, like in the case mentioned above, later disperses itself, giving the whole new form the normal staining reaction and undoubtedly otherwise taking part in the reconstruction of the cell. Figures 70 on Plate VI and 235 on Plate XVIII present such dotted pale threads of *B. azotobacter*, partially dissolved in the latter case by heating, and on page 177 we have already discussed the similar consolidation of slimy threads formed by *B. coli* and *typhi*. The photographs made by *Toenniessen* (1913) of *B. pneumoniae*, which were reproduced as figures 37–42 on Plate IV and which were explained by the author as being "mutants," make another interesting object for comparative studies. They all illustrate very clearly our preceding discussion of the reconstruction of normal cells from the symplasm. A photograph of *B. coli* published by *Kellerman* and *Scales* (1916), which was repro-

duced as figure 44 on Plate IV, furnishes another good example of new upgrowth from the symplastic stage. And a comparison of figures 99 on Plate IX (Corynebacterium, *E. de Negri*, 1916), 240 on Plate XIX (Erysipelothrix *Rosenbach*, 1909), 223 on Plate XVIII (*B. coli*, *Kellerman* and *Scales*, 1916), 247 on Plate XIX (*B. antityphosum*, *Almquist*, 1917), and 255 on Plate XX (*B. Azotobacter*, *Löhnis* and *Smith*, 1916 *b*), will indicate how a simultaneous upgrowth of the regenerative units to uniformly coccoid bodies may give rise to new forms, which in no way fit the time-honored definitions of the old form species.

This holds equally true in regard to the round regenerative bodies, whose vexatiously uniform appearance with the different species has been already discussed on page 134. If they grow up in pure culture from the symplasm, pictures like those reproduced as figures 156 on Plate XII, 219 on Plate XVIII, 244 on Plate XIX, 257 and 258 on Plate XX become visible under the microscope, leaving the investigator much in doubt as to what species they may belong.

Often, but not always, the new cells mature first at the outside of the hyalin agglomerations, and this may lead to a peculiar starlike arrangement, as has been photographed by *M. Jones* (1905) in the picture of a motile water organism (probably related to *B. radiobacter*), which was reproduced as figure 274 on Plate XXII. The author believes that this rosette formation is "apparently effected by a uniform grouping of the descendants of a single cell and is in no sense an agglutination phenomenon." But a study of the photograph in the light of my own observations upon the star formation of *B. radiobacter* make the explanation given at first more probable to me. *Beijerinck* and *Delden* (1902) found also the stars of the last-named species often, though not always, embedded in a thick slime. And *Winogradsky* (1888, p. 38) described quite similar "radiate colonies" of his Thiothrix, wherein the young threads are living together in clusters, developing from the same slimy basis. The analogous structure of the clusters of Actinomyces has been discussed on page 174.

Cladothrix, Crenothrix, and other trichobacteria have been so often described as entering a "zoogloea" stage and as growing out of slimy flakes, which frequently serve as a basis for the threads, by which they are anchored to the ground, that such pictures like figure 267 on Plate XXI, showing a young thread of our spore-forming "yellow bacillus No. 41" developing from the symplasm, must evoke considerable doubt whether the "common" bacteria may not also in this respect come much closer to the "higher" bacteria, if they are only allowed to exhibit their properties more fully than is usually granted to them. Our photograph shows that at the side of the broad basis of the thread some regenerative units are still growing up within the flake, and exactly similar round bodies have been also photographed by *Molisch* (1910, original fig. 8, Pl. II) in what he calls the "Haftscheibe" of iron bacteria. That *Meirowsky* (1914 *b*) obtained analogous results with other bacteria and that a description given by *Lachner-Sandoval* (1898) of young actinomyces threads fits our picture completely has been mentioned on pages 174 and 177. It may be added that the threads of *Leptothrix* within the human mouth exhibit the same morphological character, according to *Robin* (1853), *Miller* (1889), and *Beust* (1907).

That sometimes the outer part of the symplasm may solidify and inclose the newly developed cells like a cyst has been mentioned on page 181 as an interesting parallelism to the behavior of the Myxobacteriaceae. But it seems as if such "macrocysts" of the bacteria, as they may be called to distinguish them clearly from the microcysts discussed in Chapter II, are no regular occurrence and no species mark. *W. Winkler* (1899) and *Münden* (1907) have noticed them with *B. coli* and *diphtheriae*, where they have been missed by other authors, like *Kellerman* and *Scales* (1916) and *Almquist* (1917). The environmental conditions undoubtedly play a very important rôle in this case, although *Müller-Thurgau* (1908) perhaps went a little too far when he assumed that practically the action of tannic acid alone was to be made responsible for the formation of the interesting "bacteriocysts," which he discovered in wine. The parallelism to *Billroth's* Ascococcus (1874), *Babes'* Ascobacterium (1895), *Moreno's* Ascobacillus (1901), *Winogradsky's* Amoebobacter and Thiocystis (1888), as well as to the last-named author's zoogloea form of Nitrosomonas (1892), is so evident that the whole subject undoubtedly needs a more thorough study, which should also try to clear up the early findings of *Letzerich*, *G. A.*

Hansen and *Babes*. (See pp. 170 and 171). Peculiar pseudo-macrocysts seem to occur occasionally in the body; *J. Israël* (1878) encountered round bodies in decayed teeth wherein some "Leptothrix" was seen to develop, and *Arndt* (1880) reported that he found saliva corpuscles filled with spirochaets and that he also saw spirochaets coming out and entering these bodies.

That large clumps of symplasm may encapsulate themselves has been discovered by *Rosenbach* (1909); his photograph was reproduced as figure 242 on Plate XIX. But another photograph of *B. typhi*, published by *Almquist* (1917), which was reproduced as figure 243 on the same plate, makes it very probable that much of what represents itself as large yeast-like cells in the symplasm of many different species of bacteria is in reality such encysted lobes, made up of a deeply staining membrane and a hyalin content. In some cases the investigators have been able to branch off really yeast-like cultures, as, for instance, *E. de Negri* (1916) from her Corynebacteria, but in other cases no growth of these problematical forms could be secured, e. g., by *Maher* (1913) with *B. tuberculosis*. And after having become acquainted with *Rosenbach's* findings, it seems to me, indeed, very probable that as in *Almquist's* typhoid cultures so also those very large dark bodies visible in our photographs of Azotobacter symplasms, reproduced as figures 253 and 254 on Plate XX, are no genuine cells, but encysted lobes of the symplasm.

These bodies then would be closely related to other still more curious forms, which in our preliminary communications have been called "irregular regenerative bodies," and of which it was said on page 122 that probably "sclerotia" would be a more correct denomination for them, but that final action in this respect can not be taken at the present. The two photographs of *Bac. subtilis* and *fluorescens*, reproduced as figures 65 on Plate VI and 261 on Plate XX, may serve as illustrations. The extremely polymorphous "bacteroids" of *B. radicicola* are another well-known example. At least part of the queer spiny bodies developing from the symplasm of the micrococci also belong to this class; and the same holds true in regard to those irregular bodies of *B. cyanogenes*, pictured by *Neelsen* (1880), which were reproduced as figure 85 on Plate S, as well as to similar abnormal forms of *Streptoc. lactis*, found by *Burri* (1898) in Swiss cheese. That these bodies are nothing else than pieces of symplasm surrounded by a more or less solid, deeply staining membrane is quite obvious in many cases; and many of them merely persist for some time and then dissolve again into a more or less homogeneous mass. Others, however, are able to propagate as such, at least temporarily; those cultures of irregular Actinomyces-like rods characteristic for the micrococci belong in this class. The abnormal Streptococcus cultures of *Burri*, mentioned above, also grew as such for some time.

That as in these so also in other cases a close study of the development taking place within and from the symplasm is the best means to attack successfully many of the numerous problems concerning bacterial pleomorphism, variability, occurrence of so-called involution forms, limitation of the species, and similar points, needs no prolix discussion. It is equally obvious that chemical, physical, and biological reactions will often exert a much stronger influence when they are acting upon the symplasm than during the time the living material is standing against them in a rather stable organization within the cell. Undoubtedly, *Fokker* (1902–1903) went here, as in his heterogenetic speculations, too far when he assumed that by mixing various species of bacteria in their symplastic stage new species could be created at will, but he was perfectly right in making the following important statement (1903):

> Wo sich in einer indifferenten Flüssigkeit eine einzige Mikrobenart vorfindet, entstehen nach der Dissociation Mikroben der gleichen Beschaffenheit . . . Wo sich aber zwei oder mehrere Arten vorfinden und die dissociierten Plasmata sich vermischen, können sich aus diesem Gemisch Mikroben bilden, die die Eigenschaften der ursprünglich anwesenden in sich zu einer Einheit kombinieren, also von jeder der eingesäten einzelnen Arten verschieden sind. Auch ist die Möglichkeit nicht ausgeschlossen, dass bei der Dissociation in einer Nahrlösung, welche Bestandteile enthält, die in dem Substrate, in welchem die Mikroben erzogen sind, fehlten, diese Bestandteile auf das dissociierte Plasma einwirken, so dass letzteres Veränderungen erleidet, welche sich in den Eigenschaften der aus diesem Plasma regenerierten Mikroben kundgeben.

It is evident that the perplexing problems concerning the often so far-reaching morphological and physiological alterations of the bacteria caused by symbiosis, as well as by the change of substrate and environment, are becoming much more accessible, if the symplastic stage is

chosen as the starting point in such experiments. That a mixing of the symplasms of naturally related bacteria, like the streptococci and the diphtheroids, will lead to the appearance of interesting intermediate varieties, as mentioned on pages 40–41, is very well conceivable, just as well as or even better than the analogous facts caused by cross-breeding among the higher plants or animals. It is practically unavoidable that the reconstruction of new cells from such a mixed symplasm leads to the incorporation of elements of different parentage, so that the newly born variety (not species, as *Fokker* thought) will combine the characters of the original strains.

With the substrate it is quite similar, as *Fokker* has pointed out already. The upgrowth of the regenerative units within the symplasm is very similar to the development of bacterial gonidia within the dying or dead plasma of other plants or animals, which has been discussed on pages 148–150. That the natural varieties of the bacteria exhibit so often to such a marked degree the specific influence of their habitat is not astonishing, if one bears in mind how the very intimate contact between substrate and living matter in the symplastic stage must exert its direct influence upon the composition of the new cells.

It may be expected with certainty that renewed experiments on the effects of "cross-breeding" and adaptation of the bacteria will furnish results of great importance to bacteriology, as well as to biology generally, if they will be centered upon the symplastic stage in bacterial life. It can even not be denied that the rôle played by the regenerative units in the reconstruction of new cells from the symplasm displays many features, which remind us of the activities ascribed to the hypothetical "gemmules" of *Darwin* (1868, p. 448), the "plastidules" of *Haeckel* (1876), the "microplasts" of *Hanstein* (1882, p. 218), the "pangens" of *Vries* (1889), the "germplasm" of *Weismann* (1886, 1892), the "bioblasts" of *Altmann* (1894, p. 141), and the "physiological units" of *Spencer* (1898, p. 226). The greatest resemblance is noticeable in regard to *Spencer's* physiological units, which were declared to "possess the property of arranging themselves into the special structures of the organism to which they belong" and to be "complete aggregations of smaller chemical units, compounds of highly compound molecules." But also *Altmann's* hypotheses upon cell formation are bound to gain new interest when linked up with our new point of view. In regard to the higher organisms *Altmann* said (l. c., p. 8):

> Die Zellen sind nicht Elementarorganismen, sondern Colonien von solchen mit eigenartigen Gesetzen der Colonisation; die Zellen entstehen aber nicht durch das Zusammentreten der Kügelchen, sondern sie sind daraus in jenen geschichtlichen Perioden entstanden, die den mikroskopischen Elementen gerade so eigen sind, wie den groben Formen der Lebewesen auch.

That the theory "omnis cellula e cellula" is not so generally applicable, as *Altmann* and many other authors believed, has been pointed out on page 167. But a study of the symplastic stage in the lives of the lower organisms proves conclusively that *Altmann's* opponents, like *Hueppe* (1896, p. 2), *A. Fischer* (1899, p. 295) and *A. Fischel* (1903), erred to a still greater extent when they disputed the fundamental importance of those "granules" for the life of the cell. One has only to behold their agglomeration or their growing up to new cells under the microscope, to become quickly convinced of their being, indeed, the "elementary organisms," forming temporarily a comparatively stable association in the form of a coccus, a rod, or a spirillum, but continuing their existence unimpaired after these cells have undergone renewed dissolution. The staining reaction of these granules may change within the symplasm, as it does within the cells, where this fact has caused so many differences of opinion among the various investigators. When, for instance, *Metzner* (1903) reports that the small granules in many animal cells take the fuchsin stain while young, but become unstainable when they grow old, and that in the latter stage they serve the metabolism of the cell, he is touching evidently the same fundamental fact which manifests itself in the development of the pale cells from agglomerations of well-stained regenerative units, as mentioned above, as well as in the variable behavior of the gonidia within the bacterial cell, as was discussed in Chapter II.

The physiological value of the symplastic stage for the bacterial life is very clearly indicated by the two facts, that the symplasm is formed from time to time in cultures kept for long

periods, but that it is also often produced by very young cultures immediately after they have been transplanted to a new substrate. *Buchanan* (1918) is of the opinion that the bacterial development proceeds regularly in seven phases, which are defined by mathematical formulas. However, his assumption that at the beginning always a "stationary" period and "lag" be noticeable, and that the "logarithmic phase of growth," the "phase of negative acceleration" and the "maximum stationary phase" be followed with mathematical certainty by the "accelerated death rate" and the "logarithmic death rate," is not in accordance with many well-established facts. When *Chesney* (1916) studied the so-called lag in the development of newly transplanted cultures, he noticed that no lag occurred when the transfers were made at the time of maximal growth, but that it was always exhibited by older material. However, not only old cultures, also young ones may show this "lag." When we transferred our Subtilis and Azotobacter cultures every morning and evening during several weeks, always from and to the same substrate (meat agar for Subtilis, mannite agar for Azotobacter), no lag was noticeable in the growth of the subcultures for several days, while it was very pronounced during the next days, then again immmediate upgrowth took place, again a period of lag followed, and so on. Microscopic examinations showed clearly that either the cells propagated as such, or that they first entered the symplastic stage, and it was especially these experiments which we accepted as evidence of the alternation between both modes of life (*Löhnis* and *Smith*, 1916 *a*, p. 679). That the same alternation takes place when cultures are kept for a longer period without being transferred to new substrates is indicated by the results obtained by *Römer* (1909) and by *Springer* (1913), which have been quoted on page 28, and it is proven by our continued studies of all our 24 Azotobacter strains, which exhibited very distinctly in successive microscopic tests their persistent passing through the various phases of their life cycle, when kept permanently in the same solution (without any transfer) for more than a year. That under such conditions metabolic products and other external influences will act besides the internal causes, which were practically solely responsible for the results mentioned above, is not to be doubted. In nature, however, the situation is the same. And it will be advisable not to be too quick in declaring changes in form and function, often noticeable in old cultures, as being "merely" the result of "involution or degeneration," caused by the "detrimental effect of the metabolic products." It is true that secondary and tertiary colonies, growing on old agar slants, often abound in "abnormal" cells, but as these cells, according to *Preisz* (1904) and others, are usually more resistant than those which grew first, and the so-called involution forms, as was fully discussed in Chapter I, are often more numerous in young than in old cultures, it seems best to apply the newly won knowledge of the rôle played by the bacterial symplasm, to these facts and to make them the object of renewed and more thorough studies. Why *Fürst* (1914) found in the course of his experiments upon the variability of *Vibrio proteus* that in the 4-months-old cultures a period of rest preceded the return of the original type of growth, is easily to be understood, and it is equally obvious why apparently fully stabilized varieties, that have remained constant through hundreds of transfers made during several years, eventually may return to the original type. A close investigation upon the reproduction of the different types of cells from the symplasm will elucidate all such experiments to a very considerable degree.

That practically all of the symplasm is used up for the reconstruction of the new cells is an interesting sign of Nature's economy, which was first recorded by *W. Winkler* (1899), and which became again very conspicuous in many of our experiments. (See *Löhnis* and *Smith*, 1916 *a*, pp. 680 and 692, and the photographs reproduced as figs. 215, 216, 219, 220, 223, 243, 256–261, and 263 on Pl. XVIII–XXI.)

In an interesting paper upon autolysis, wherein the participation of assimilation and dissimilation in all vital processes is thoroughly discussed, *Nicolle* (1913, p. 446) makes the following statement, which is of special importance for our subject:

> Lorsque l'assimilation et la désassimilation s'équilibrent harmonieusement, . . . c'est la vie stationnaire . . . Quand la désassimilation l'emporte, mais que l'assimilation conserve une intensité suffisante, c'est l'atrophie. Lorsque la désassimilation l'emporte, tandis que l'assimilation tombe au-dessous d'une certaine valeur minime, c'est l'autolyse. Quand l'assimilation l'emporte, mais que la désassimilation conserve une intensité suffisante, c'est l'hypertrophie,

voire l'hyperplasie. Lorsque l'assimilation l'emporte, tandis que la désassimilation tombe au-dessous d'une certaine valeur minime, c'est l'autocoagulation, phénomène inverse de l'autolyse; c'est la naissance de formes résistantes, rigides, coagulées, condensées . . . Chose curieuse, les deux tendances opposées se partagent quelquefois la meme cellule (sporulation rapide, lors d'inanition brutale) donnant ainsi l'image d'une action et d'une réaction également excessives.

But in the same manner as the French proverb "Les extrêmes se touchent" is applicable to this latter case, it holds equally true in regard to many instances, where the new forms emerging from the symplastic stage are not, as might be expected at the first moment, normal vegetative cells, but, quite to the contrary, regenerative bodies, rods with endospores, and all kinds of "giant" forms, which are usually classed as signs of involution and degeneration, and which only in the course of their further development gradually resume that harmonious equilibrium between assimilation and dissimilation which, according to the French author, characterizes stationary life.

2. THE SYMPLASTIC STAGE IN THE DIFFERENT GROUPS OF BACTERIA.

That the so-called Ascococcus of *Billroth* (1874) does not represent a special genus, but is merely a type of growth of micrococci developing from the symplastic stage, is hardly to be doubted, despite an opposite statement made by *F. Cohn* (1875, p. 151). A drawing published by the latter author has been reproduced as figure 275 on Plate XXII (from original fig. 5 on Pl. V), where it may be compared with another picture (fig. 276), published by *Rabe* (1886, original fig. 2 on Pl. IV) of his *Micrococcus botryogenus*, which exhibited these actinomyces-like agglomerations only within the tissue, while on artificial substrates the development did not differ from that of any other Micrococcus.

A characteristic photograph of *Micrococcus candicans* growing up from the symplastic stage has been reproduced as figure 216 on Plate XVIII (from our second preliminary paper, 1916 *b*). All intermediate steps from the smallest regenerative units up to full grown cocci, like those shown in figure 1 on Plate I, are clearly discernible. The peculiar clusters of irregular, spiny, rodlike regenerative bodies, in figures 2 and 8 on Plate I, described in Chapter I as a characteristic type of growth of the micrococci, are equally the result of a complete transformation of flakes of symplasm of *Microc. candicans*.

Figure 264 on Plate XXI (taken from our second paper, 1916 *b*, original fig. 53) demonstrates the analogous behavior of a Sarcina. Again at the edge of a large flake of symplasm of *Sarcina flava* the gradual development of the regenerative units to large cells is to be seen. And in figures 16 and 17 on Plate II the final transformation of the large cells into normal sarcinae has been shown. Before having reached their definite shape, the packets are often connected by more or less solid bridges, which are clearly visible in figure 16, and which have been described before by *Sauerbeck* (1909) in a paper upon a *Sarcina mucosa*, of which several packets also frequently were seen to be enclosed in a slimy "capsule" (probably of symplasm).

The ability of staphylococci and gonococci to produce in 3–4 weeks old cultures "white pleomorphous clumps," similar to those of the so-called syphilis bacillus, as shown in figure 217 on Plate XVIII, has been mentioned already by *Niessen* (1898). But it was *Herzog* (1913) who first pointed out that this passing over of the gonococci into such "verquollene Schleimmassen" is of considerable etiologic importance, and that these clumps should not be lightly discarded as dead.

Analogous observations concerning streptococci were made by *Billroth* as early as in 1874, upon which he reported (p. 12):

> Das Plasma tritt in Form amorpher, körnig-schleimiger Substanz aus den Kugeln hervor . . . Ob damit das Pflänzchen abgestorben ist, will ich dahin gestelltsein lassen.

Why he did not succeed in getting a new development with these organisms, while in other cases he secured positive results with similar bacterial "plasmodia," must be left undecided. That it was undoubtedly the regenerative units and round regenerative bodies growing in and from the symplasm of lactic acid streptococci in milk which misled *Fokker* (1901) to his anachronistic hypothesis of the heterogenetic origin of milk bacteria from casein granules has

been discussed on page 172 and illustrated by figure 214 on Plate XVIII. Figure 215 on the same plate pictures, on the other hand, a flake of symplasm of the same species which, however, is transforming itself directly into normal vegetative cells of *Streptococcus lactis*. That as with other bacteria, so also with this species, the symplasm may break up occasionally into entirely irregularly shaped regenerative bodies may be concluded from an observation made by *Burri* (1898), who discovered in faulty Swiss cheese colonies of an organism, belonging into the group of *Bact. Guentheri* (*Streptoc. lactis*), which besides a few normal cells contained numerous irregularly curved and distorted forms, which, however, were able to multiply as such for some time, just as the analogous irregular regenerative bodies of the micrococci are inclined to do.

The findings of *Bernhardt* (1911), *Hoefer* (1911), and of *Mallory* and *Medlar* (1916) concerning the causative agent of scaralatina, which have been quoted on page 184, represent another important contribution to our knowledge of the symplastic stage in the life cycle of the streptococci. And it is very probable, too, that in the case of poliomyelitis analogous results will be reached. The photograph published by *Rosenow* and *Towne* (1916), which was reproduced as figure 9 on Plate I, looks much like a picture of symplasm producing new cells, and that various filterable vira have been found in close connection with such slimy, granular, differently staining masses, characteristic for this stage, was mentioned on page 185.

The small micrococci of about 0.15μ diameter, embedded in thick zoogloea masses, which *R. Koch* (1878) found instead of septicaemic bacilli in spreading abscesses in rabbits, and of which he discovered that even the unstainable homogeneous part proved to be infective (causing septicaemia), may well be accepted as the regenerative units of *B. septicaemiae; Koch's* drawing, reproduced as figure 211 on Plate XVII, indicates clearly that he had large agglomerations of symplasm under the microscope.

In the case of *B. radicicola* the symplasm and the various growth developing from it have been the cause of widely divergent conclusions reached by the different authors. As was mentioned on page 180, the organism has been placed among the Myxomycetes as well as among the Myxobacteria. *Frank* (1879) thought at first that the infective threads and the branched and budding forms developing from them should be accepted as mycelium and haustoria of a fungus. Later (1887), with the help of his pupils *Brunchorst* (1885) and *Tschirch* (1887), he deprived it entirely of its microbial nature; the "bacteroids" were now declared to be cell products of the legume. Two years later, however, after *Beijerinck* (1888) had isolated *B. radicicola*, *Frank* (1889) discovered that the infective threads be "plasmodia" of a peculiar "Rhizobium leguminosarum" and the "bacteroids" some kind of "mycoplasma." But in 1890 the German author also came to the conclusion that bacteria are to be made responsible for the various types of growth within the plant. *Moëller* (1885) also classed the alder organism at first among the Myxomycetes, because he saw the finely granulated plasma differentiate itself into round "spores," i. e., regenerative bodies, while he later (1890) assumed it to be a "unicellular hyphomyces" (*Frankia subtilis*), producing globular, oval, or pear-shaped "sporangia" of 4–6μ diameter at the end of the "hyphae," wherein "spores" are said to develop, which later reproduce a new "mycelium." The analogous change of opinion is also to be found in *Prażmowski's* (1888–1890) important papers upon the nodule organism of the leguminous plants. At first the "Knöllchenpilz" was described as forming large cysts, which after being placed in water liberated their content, made up of "bacteroids" embedded in a slimy, plasmatic substance. But later these cysts were accepted as being encapsulated colonies of bacteria. *Laurent* (1890) was inclined to place *B. radicicola* at the side of *Pasteuria ramosa* on account of the similarity noticeable between the "bacteroids" of the nodule organism and the branched clubs characteristic of *Metchnikoff's* organism. *Morck* (1891) found out that their regular bodies occurring in the root nodules of different legumes are either able to reproduce directly small motile bacteria or that they break up at first into round regenerative bodies. Their resistance against acid and alkali proved to be comparatively high. The granular plasma, visible in the youngest part of the nodules, was seen to produce either round or irregular forms or directly small rods. When studying the nodules of Alnus *Hiltner* (1898) obtained very similar results. Irregular slimy clumps and threads, containing rods, were seen, as well as "sporangia," produced by the rods or the threads,

which divided themselves into round "spores," which in their turn reproduced new rods. A later publication by *Hiltner* and *Störmer* (1903) contains those interesting photographs reproduced as figure 236 on Plate XVIII (from original fig. 8 on Pl. II), showing the "sporangia" of Alnus, and as figures 271 and 272 on Plate XXI (from original figs. 5 and 6, Pl. II), illustrating the analogous development of round bodies within the nodules of clover and pea, respectively. *Shibata* (1902) reported that the round bodies of Alnus may occasionally enter a process of multiple segmentation, similar to that sometimes observed with microcysts of streptococci and of other bacteria, which has been discussed on page 143. As figure 273 on Plate XXI a photograph has been reproduced (*Löhnis* and *Smith* 1916 *a*, original fig. 34), showing a flake of symplasm from a root nodule of red clover, which is producing clubbed and branched "bacteroids" as well as small, round regenerative bodies.

An excellent photograph of round regenerative bodies, found in cultures of *B. coli* by *Kellerman* and *Scales* (1916), has been reproduced as figure 44 on Plate IV. It should be compared with *Hiltner* and *Störmer's* Alnus picture (fig. 236 on Pl. XVIII). That also in this case the large bodies grew up from the symplasm is indicated by other details visible in the photograph. The hyphae-like threads of *B. coli*, shown by the first-named authors in two other pictures (figs. 45 and 224 on Pls. IV and XVIII), make interesting counterparts to the "infecting thread" of *B. radicicola*. In figure 223 on Plate XVIII the simultaneous and uniform upgrowth of the regenerative units of this species is equally well demonstrated. That the symplasm of *B. coli* may sometimes exhibit amoeboid movements has been observed by *W. Winkler* (1899) and by *Münden* (1899).

The picture published by *Almquist* (1916) of the various cell forms of *B. typhi*, which was reproduced as figure 243 on Plate XIX, shows very clearly the consolidation of the plastic substance into slimy threads and large globules. *Meirowsky's* (1914 *b*) drawings of what he calls "umbels" of paratyphoid and enteritis bacilli exemplify the upgrowth of new rods and threads from the symplasm. A few reproductions are to be found on Plate XIII (fig. 178, right lower corner) and on Plate XIV (second column).

That in cases of rhinosclerom the formation of symplasm by the causative agent is rather conspicuous has been indicated by the early findings of *Cornil* and *Alvarez* (1885) and of *Klebs* (1887).

A good illustration of the regeneration of new cells from the symplastic stage among the lactobacilli is given in the photograph of *B. acidi propionici c*, published by *Almquist* (1917) and reproduced as figure 246 on Plate XIX. The "vesicular forms" of *B. bifidus*, which *Tissier* (1900) considered to be degenerative, are probably, like similar forms frequently to be found with *B. radicicola, coli, pneumoniae, Azotobacter*, etc., another type of new cell formation from the symplasm. *Tissier's* drawing, which has been reproduced as figure 8 on Plate C (the "formes vésiculeuses" are to the right), should be compared with the photographs made by *Toenniessen* (1913) of *B. pneumoniae*, reproduced as figures 38–41 on Plate IV; the gradual development of regular cells from these irregular intermediate forms is especially well discernible in this case. Other data in regard to the symplastic stage of members of the *B. pneumoniae* group are given in a paper by *Jehle* (1902).

A *Bac. tubifex*, described by *E. Dale* (1912) as causative agent of a disease of potato leaves, was seen to produce infecting threads of the same appearance as those of the nodule bacteria, and probably also of the same physiological quality.

The important findings of *Rosenbach* (1909) concerning the symplastic stage of *B. erysipelatos suum* (*B. erysipeloides*) have been fully discussed on page 176. Highly interesting photographs of his paper were reproduced as figures 239–242 on Plate XIX, and as figures 27–29 on Plate III.

The mycelial upgrowth shown in the last-named picture invites comparison with a similar photograph made by *Rowland* (1914) of *B. pestis* (see fig. 30, Pl. III), while other data relating to the symplastic stage of this organism have been observed, but not correctly interpreted, by *N. K. Schultz* (1901, see figs. 218–221 on Plate XVIII and previous discussion on p. 176).

The agglomerations of growing regenerative units of the bacillus isolated by *P. Th. Müller* (1913) in cases of typhus exanthematicus, which have been reproduced as figure 22 on Plate II,

deserve to be compared with figures 216, 223, 240, 247, and 255 on Plates XVIII–XX, picturing the same phase in the life cycles of other bacteria (*M. candicans*, *B. coli*, *erysipeloides*, *antityphosum*, and *azotobacter*, respectively). In addition, figure 24 on Plate II clearly represents another type of upgrowth from the symplasm of *Müller's* organism; although a glance at the torn flakes of symplasm visible in the field leaves no doubt that a more carefully made preparation would have presented much better objects for comparative study.

In *Hauser's* first publication upon his Proteus (1885) the symplasm with its regenerative units and their development to new bacilli has been fairly well described.

Analogous observations with various Pseudomonas species were made by *Fuhrmann* (1906–1908). One of his photographs is to be found as figure 238 on Plate XIX. Various phases in the development of different cell forms of *B. fluorescens* from the symplastic stage have been reproduced as figures 259–263 on Plates XX–XXI (from our second paper, 1916 *b*, original figs. 8, 49–51, 63). The photograph shown as figure 265 furnishes another good illustration of how different the cells of "typically" short rods may appear under such conditions; the picture was made from an aerobic cellulose destroying organism, *Bact. acidulum*.

What *Omelianski* (1899) described as a new nitrite-forming organism should be studied again, as its photographic picture, reproduced as figure 268 on Plate XXI, makes it practically certain that merely a clump of round regenerative bodies has been seen, which grew up from the symplasm, such as is shown in figures 257 and 258 (Plate XX) from *B. azotobacter*, or in figure 219 (Pl. XVIII) from *B. pestis*. The two other photographs of Nitrosomonas, made by *Winogradsky* (1892) and reproduced as figures 269 and 270 on Plate XXI, are good illustrations of macrocyst formation. The presence of the large round cells within the "zoogloea" (fig. 270) strengthens our belief, expressed on page 135, that the so-called Nitrosococcus of *Winogradsky* (shown in fig. 198 on Pl. XV) is nothing but a type of regenerative bodies of Nitrosomonas.

Not many data are available at present concerning the symplastic stage of spore-forming bacilli. That it plays an important rôle in the life history of *B. anthracis* has been repeatedly discussed by *Fokker* (1881–1882 and 1902). *Young* (1914) made a few remarks upon so-called sporoblasts, apparently being agglomerations of regenerative bodies growing up from the symplasm and developing to spore-forming rods. Our own preliminary studies upon the life cycles of *B. azotobacter* and related sporogenous bacilli, however, leave no doubt that also within this group of bacteria correct and complete results will not be reached until detailed investigations have been carried out in this direction. The photographs of *B. azotobacter* (figs. 70 on Pl. VI, 225–231 on Pl. XVIII, 250–258 on Pl. XX), of *B. subtilis* (figs. 65 on Pl. VI, 233 on Pl. XVIII), of *B. malabarensis* (fig. 266 on Pl. XXI) and of the "yellow bacillus No. 41" (fig. 267 on Pl. XXI) will suffice to indicate that very many interesting problems are awaiting adequate research.

That vibrios and spirilla also pass through the symplastic stage has first been noticed by *Finkler* and *Prior* (1884–1885) and by *Weibel* (1887). *Dowdeswell* (1889–1890), however, is to be credited with having made the first more thorough investigations upon this subject. "Cocci" embedded in amorphous masses have been also found by *Jorge* (1896) in cultures of a vibrio isolated from water, but their true character was not ascertained. *Almquist* (1916) got an interesting culture of fairly resistant regenerative bodies from a cholera culture, heated up to 60 C.; in figure 244 on Plate XIX the upgrowth of these round forms from the symplasm is very well illustrated. It is not improbable that *Hueppe* (1885) had similar objects under the microscope when he made the sketch of a "zoogloea" containing round bodies which is visible in the center of figure 49 on Plate M. *Albrecht* (1881) discovered in blood cultures of *Spirochaeta Obermeieri* irregular clumps of dark points, which permanently changed their form, and he also observed the formation of new spirochaets from them. The more recent findings, recorded by *Meirowsky* (1914 *b*) with various spirochaets and by *Leishman* (1918) with *Spirochaeta Duttoni*, are in perfect agreement with those early discoveries. On Plate XIV, in the lower part of the second column, some interesting drawings made by *Meirowsky* of spirochaets

growing up from the symplasm are to be seen. Figure 86 on Plate S should be compared with them.

With the Mycobacteria some more data are available. The early findings of *Letzerich* (1873–1876, cf. page 170) have, of course, not been obtained with pure cultures of diphtheria bacilli; nevertheless, they invite further investigation. That such macrocysts as have been seen by this author may be found, indeed, in pure cultures of *B. diphtheriae* has been made very probable by results recorded by *Münden* (1899). Formation of round regenerative bodies from amorphous masses in old diphtheria cultures, i. e. from the symplasm, has been noticed by *Spirig* (1903) and by *Balfour* (1911 *d*). A fairly good photograph of various cell forms of *B. diphtheriae*, developing from the symplastic stage, has been published by *Almquist* (1917); it is reproduced as figure 245 on Plate XIX. That the amorphous agglomerations present in old cultures of *B. xerosis* are equally able to produce a new growth has been ascertained by *P. Ernst* (1888). On the other hand, it was evidently not correct, when *Morse* (1912) maintained that only one group of pseudo-diphtheria bacilli (*B. hoagii*) be characterized by the fact that in old cultures the bacilli "fuse into poorly staining masses," whereas *B. xerosis* and *Hofmanni* are said not to exhibit such changes. The photograph made by *Mellon* (1917) of diphtheroids from the lung, reproduced as figure 249 on Plate XIX, furnishes additional evidence in this respect. The publications of *Niessen* (1898, 1908) upon his so-called syphilis bacillus contain several interesting data concerning the symplastic stage of diphtheroid organisms, of which, however, only very cautious use should be made, on account of the uncritical manner in which they have been gathered and reported.

That with leprosy the symplastic stage of its causative agent is of considerable frequency and importance may be seen from the publications of *G. A. Hansen* (1880–1882), *Babes* (1883, 1907), *Lutz* (1886), *Czaplewski* (1898), *Barranikow* (1900), *Pernet* (1902), and *Meirowsky* (1914 *b*).

Equally numerous are the observations upon finely granulated or entirely homogeneous "zoogloea" masses in tuberculosis and in cultures of *B. tuberculosis*. The contributions made in regard to this subject by *Klebs* (1883), *Babes* (1883), *Malassez* and *Vignal* (1883–1884), *Amrusch* (1886), *Schroen* (1886–1904), *Metchnikoff* (1888*a*), *Arrigo* (1900), *Meier* (1903), *Maher* (1910–1913), and *Meirowsky* (1914 *b*) have already touched many points, which should be thoroughly studied. Especially the work of *Schroen*, though rather incomplete in itself, is undoubtedly worthy to be taken up anew and carried out in a more satisfactory manner; the data collected with *B. radicicola*, and the peculiar behavior of this organism within the root nodules of leguminous and of other plants, reveal many striking resemblances to what has been described and pictured by *Schroen* concerning his "new phthisiogenic microbe." That this is no fungus, as was assumed by its discoverer, is beyond doubt, despite the incompleteness of the report. The thick slimy threads, accepted as mycelia, resemble very closely those produced by *B. radicicola* within the plant.

The granular mass, found by *Crookshank* (1896), *Mertens* (1903), and others in the center of many clusters of Actinomyces, is obviously an unchanged part of symplasm, and the description given by *Lachner-Sandoval* (1898, quoted on p. 174) concerning the development of young threads of Actinomyces from flakes of symplasm, could be accepted as pertaining at the same time to any other kind of rod-like bacterium. *Meirowsky's* drawings (see Pl. XIII, fig. 178, No. 57, and Pl. XIV, second column, "Paratyphus B") and our photograph of the spore-forming yellow bacillus No. 41 (fig. 267 on Pl. XXI) fit *Lachner's* description completely.

The development of new threads of Cladothrix from round gonidia (or regenerative bodies ?), which are embedded in a "zoogloea" (symplasm), has been illustrated by *Billet* (1890) in the upper part of the sketch reproduced as figure 70 on Plate P. That the microgonidia of Crenothrix often enter the symplastic stage before new threads are reproduced has been pointed out by *F. Cohn* (1870) and by *Zopf* (1879). And *Perty* wrote already in 1852 (p. 215) in regard to Gallionella ferruginea:

> Nach der Zerstörung der Hüllen ballt sich der Inhalt, der mehr oder minder die Form von Körnchen annimmt, die von 1/1500‴ bis zu unmessbarer Kleinheit vorkommen, in Haufen zusammen. Diese manchmal unregelmässigen Körnchen scheinen eben sowohl zur Vermehrung zu dienen, als die regelmässigen, innerhalb der Fäden erzeugten, kugligen oder elliptischen Sporen.

That the so-called "Haftscheibe," considered by *Molisch* (1910) to be quite characteristic for certain species of iron bacteria, may be also correctly classified as a remnant of the symplastic flake, which produced the thread, is hardly to be doubted. On the other hand, the statement made by *Winogradsky* (1888, p. 40) that *Zopf* had been wrong in attributing to Beggiatoa the ability to grow sometimes attached to the substrate, and that such sulphur bacteria be representatives of a special genus Thiothrix, will have to be reconsidered in the light of the new facts mentioned above. Evidently all rod- and thread-like bacilli are able to make use of their symplasm for attaching themselves to their substrates if the conditions under which they are living are favorable to such an arrangement.

3. CONCLUSIONS.

From the details discussed on pages 166–195 the following conclusions can be drawn concerning occurrence and formation of the symplasm and the regeneration of new cells from the symplastic stage:

(1) All bacteria live, in vivo as well as in vitro, alternately in an organized and in an amorphous stage. By the partial or complete dissolution of vegetative and reproductive cells a plasmatic mass, the symplasm, is formed, which after a period of rest and according to circumstances may transform itself into new cells of the same or of a more or less modified character. It has been found, for instance, in young as well as in old cultures of *Microc. gonorrhoeae, candicans*, and other species of Micrococcus; various streptococci; *Bact. pneumoniae, rhinoscleromatis, coli, typhi, paratyphi, enteritidis, pestis, septicaemiae, erysipelatos suum, proteus, bifidus*, and other lactobacilli; Nitrosomonas; *B. radicicola* and *fluorescens; Bac. anthracis, subtilis*, and *Azotobacter; Vibro cholerae* and *proteus;* various spirilla and spirochaets; *Corynebacterium diptheriae* and *pseudo-diphtheriae; Mycobact. tuberculosis* and *leprae;* different Actinomycetes and trichobacteria. Within the body the presence of bacterial symplasm has been recorded in cases of gonorrhoea, trachoma, variola. scarlatina, poliomyelitis, meningitis, endocarditis, septicaemia, rhinoscleroma, anthrax, pseudo-tuberculosis, tuberculosis, leprosy, malignous granulom, diptheria, actinomycosis, actinobacillosis, recurrens fever and syphilis. It participates in the formation of hyalin and amyloid substances within the body. Observations made by *Pineau* in 1845 and by *Perty* in 1852 have already indicated that all microscopic life starts from the symplastic stage, which, however, is not entirely absent in the cell life of the higher organisms. The earliest complete description of the symplastic stage of bacterial life has been published by *Lankester* in 1876. The so-called autolysis of bacteria is in part identical with the formation of the symplasm. The dissolution of the cells should not be considered synonymous with death of the living matter itself, and the regeneration of new cells from the symplastic stage is not to be accepted as heterogenesis, although this has been done by *Bastian, Fokker* and others.

(2) The formation of bacterial symplasm proceeds always in two phases: First, the cells agglomerate to smaller or larger clumps; second, a more or less complete dissolution of the cells takes place, resulting in a crumbly or slimy mass, assuming the shape of flakes, irregular clumps or regular spheroid bodies, and being sometimes endowed with amoeboid motility. The dissolution of the agglomerated cells leaves either the empty cell walls as shadows, but still clearly visible, in the field, or they, too, are disintegrated, forming a more or less homogenous symplasm of an either hairy, granular, or entirely amorphous, hyalin structure, of variable staining qualities, and of fairly high resistance against acids and alkali. The different types of symplasm may be found with the same species of bacteria; one type may pass into the other. Presence or absence of amoeboid motility is no species mark; the same holds true in regard to an occasional encystment of the symplasm. All kinds of vegetative cells as well as of reproductive organs of the bacteria are able to enter the symplastic stage. Irregular regenerative bodies, gonidangia, and liberated gonidia (including the filterable ones) are especially inclined to produce symplasm, and even endospores may do the same.

(3) The reconstruction of new cells from the bacterial symplasm follows various lines, according to internal as well as external conditions (quality of the symplasm, environment, and

technique). At first always regenerative units become visible, which either grow up separately to new cells, or of which several may agglomerate and surround themselves with a uniting membrane thus forming at once full-grown cells. Usually the reconstruction starts at the edge of the symplastic flakes or clumps, occasionally leading to a distinctly star-like grouping of the new cells; sometimes, however, the transformation takes place simultaneously throughout the whole mass. The new cells formed are as a rule regenerative bodies of round or irregular shape, but normal vegetative cells may be also produced immediately. Endospores, too, may develop at once within the new cells. A uniform appearance is rather rare among the newly constructed cells; usually they are more or less pleomorphic. A special type of growth sometimes to be found in such cultures are broad, slimy threads, often of irregular outline, which by contraction or by segmentation reproduce normal vegetative cells. Like other irregular regenerative bodies they have been improperly classed as "involution forms." Generally all of the symplasm is transformed into new cells; occasionally, however, the outer part of it becomes membraneous and incloses the whole colony of newly developed cells as a "macrocyst," or a small flake of symplasm remains at the basis of a newly formed thread, fixing it to its substrate. All the different possibilities mentioned may be found with the same species of bacteria. Macrocysts have been seen with micrococci (Ascococcus), *B. radicicola*, Nitrosomonas, Ascobacterium, Ascobacillus, *Mycobact. leprae*, and with various sulphur bacteria (Amoebobacter, Thiocystis, Clathrocystis, and *Bacterium rubescens*); they indicate a closer relationship between *Bacteriaceae* and *Myxobacteriaceae*.

(4) As the various subcycles within the life cycles of the bacteria are connected by the symplastic stage, a thorough study of the regeneration of the new cells from the symplasm is essential for securing a correct knowledge of the principles governing the pleomorphism and the variability of the bacteria. Biological, physical, and chemical factors exert usually their most pronounced influence during this phase of the life cycles of the bacteria, which in their turn are at this time in a much better position to adapt themselves to changed environmental conditions, than they are during their cellular life.

IV. CONJUNCTION.

Our studies upon the life cycles of the bacteria led us to the conclusion (*Löhnis* and *Smith*, 1916 *a*, p. 700) that besides the formation of the symplasm another mode of interaction between the plasmatic substances in bacteria cells is generally to be found, consisting of the direct union of two or more individual cells. We called this process "conjunction," because frequently more than two cells are united, and a connecting bridge (yoke) is sometimes, but not always, visible; therefore, the terms "copulation" and "conjugation" are not well applicable.

Conjunct cells were constantly seen in cultures two to four days old. The conjunction always preceded the formation of the gonidia, of lateral and terminal regenerative bodies, as well as of exo- and endospores. The latter, too, sometimes entered the conjunct stage.

The formation of connecting bridges, first seen with large Azotobacter cells, reminded me of a similar observation made occasionally by *Förster* (1892), who found that in freshly collected living material of Chromatium Okenii, during the first 3 days, often a "primitive copulation" was noticeable, characterized by the formation of cylindric unstained bridges, leading from and to the unstained inner part of 2, 3, or more neighboring cells. Sometimes a knoblike inflation became visible in the middle of the bridge, and it was also no rare occurrence that only a half bridge was protruding from a single cell. No conspicuous change was seen to follow the act of "copulation," but the cells were especially large at this time, while they later lost in size as well as in vitality.

This, however, was the only confirmative finding which we could cite in our first preliminary report (1916 *a*, p. 687), though we pointed out in addition that conjunction of the bacteria, like their budding and the formation of the symplasm, has not only been seen by many bacteriologists, but also has been unknowingly reproduced in several illustrations in our daily used textbooks.

As figures 278–294 on Plates XXII and XXIII pictures are given, which may illustrate the appearance of various species in the conjunct stage. Figure 278 has been taken from *Förster's* paper. It makes a good counterpart to our Azotobacter photographs, No. 279–283. Figure 284 presents spores of Azotobacter in conjunction; the fine bridges are clearly noticeable also at some isolated spores. Figure 285 shows *B. fluorescens*, figures 286 and 287 *B. subtilis*. Figure 288 is a photograph of *B. Chauvoei*, made by *Itzerott* and *Niemann* (1895, original figure 48); figure 289 was taken from a contact preparate of a colony of *B. fluorescens*, made by *Axelrad* (1903, original figure 22); figure 290 shows *Bact. esterificans Stralauense*, photographed by *Maassen* (1899, original figure IX, 1); figure 291 was made by *Guenther* (1906, original figure 8) from a colony of large bacilli, isolated from a straw infusion; figures 292 and 293 are parts of a picture of the hay bacillus, published in the textbook of *Hiss* and *Zinsser* (1914, original figure 125); and figure 294 is another Azotobacter photograph, made by *Walton* (1915, original figure II, 8). By a careful examination of these pictures the various modes of uniting, which often replace the bridges between the cells, will be easily discovered. Especially a peculiar beak-like development of an end of a cell, stretching out to the side of another cell, is very striking. Sharp bents of the rods are equally conspicuous, as are the T and V formations, while little swellings or small droplets, sometimes noticeable at the touching points, will reveal their presence upon close scrutiny.

It goes without saying that the process itself is much better to be studied with the living material, and reproductions from stained preparates can only convey a more or less incomplete impression. But good photographs of living cells showing conjunction are hardly obtainable, and as with the symplastic stage, again direct microscopic studies are indispensable for reaching a correct view of the subject.

In his textbook on bacteriology *A. Fischer* (1903, p. 42) states very distinctly:

Geschlechtliche Fortpflanzung ist bei den Bakterien noch niemals, auch nicht andeutungsweise beobachtet worden.

That he did not know, at least, *Förster's* paper, which was published in the "Centralblatt für Bacteriologie," makes it very doubtful whether he was entitled to make such a strict statement. Numerous other observations, to be recorded on the following pages, are equally in open conflict with *Fischer's* attitude as well as with the standpoint taken by many other writers.

It was pointed out in the foregoing chapters that *R. Koch, Gaffky, Flügge,* and *Fraenkel* were undoubtedly wrong, when they established their rigid monomorphistic doctrine, that *Brefeld* as well as *Migula* were not in accordance with well-established facts when they asserted the occurrence of various types of reproductive organs among the bacteria to be a priori impossible, and that it was a serious mistake when *R. Koch* and *Loeffler* lightly discarded all that was already known at their time upon the symplastic stage of the bacteria. But these erroneous views are still upheld in many bacteriological textbooks, despite the very numerous facts which conclusively prove their inaccuracy. Concerning the occurrence of sexual processes among the bacteria much less data are available, but they are numerous enough and of sufficient weight to recommend the adoption of a more correct view than that held by *A. Fischer.*

It is to be readily admitted that for the practical bacteriologist a knowledge of the occurrence of sexual processes among the bacteria is of much less importance than a thorough acquaintanceship with their pleomorphism, their various modes of reproduction, and with their alternating between cell life and symplastic stage. This, however, does in nowise interfere with the great scientific interest of the subject.

Before taking up the data collected from the bacteriological literature, it seems advisable to discuss briefly a few points, which will be helpful for securing a better understanding and a more correct valuation of what has been done thus far by bacteriologists.

It has been emphasized already by *Darwin* (1868, pp. 431, 432) that sexual reproduction is not so very different from asexual reproduction, and that it is an error to assume that a bud differs essentially from a fertilized germ, though undoubtedly "beings produced sexually are much more liable to vary than those produced asexually." According to *Spencer* (1898, p. 265) the terms asexual and sexual multiplication are equivalent to cell reproduction and cell generation. *Delage* (1895, p. 117) makes the following statement:

Le conjugaison est bien véritablement l'intermédiaire entre la reproduction asexuelle par spores et la reproduction sexuelle par oeufs et spermatozoïdes . . . La conjugaison va nous présenter une série de formes qui par une extrémité confinent à la reproduction asexuelle, . . . et par l'autre passent à la reproduction sexuelle.

Sachs (1875, p. 203) distinguished between asexual generation, with asexual reproductive cells, developed independently without foreign aid, and sexual generation, i. e., development of new cells with the aid of another cell. If in the latter case the uniting cells are uniform, the process was called conjugation, if they are conspicuously different, fertilization.

Kruse (1896 *b*, p. 83) says:

Partielle Konjugation heisst der bei Infusorien weit verbreitete Vorgang, bei dem sich gleichartige Individuen vorübergehend mit einem Teile ihres Körpers vereinigen, je einen ihrer Mikronuclei mit einander austauschen und sich wieder von einander trennen. Ausstossung von Richtungsspindeln, Kern-Auflösung und -Neubildung findet dabei nicht statt.

It is obvious that this definition fits very closely to that type of conjunction which is most frequently exhibited by the bacteria.

According to *Prowazek* (1907 *b*) sexuality is an elementary process inherent to the living matter and either already discovered or expected to be found with all lower plants and animals. *Doflein* (1909, p. 158) states that as far as the protozoa have been studied multiplication by segmentation can not go on indefinitely, and that sometimes after a few, in other cases after thousands, of purely vegetative generations sexual processes are taking place, either in the form of copulation (i. e., complete uniting of two cells) or as conjugation (i. e., interaction between the nuclear substances of various cells).

With special reference to sexual processes among protists *Hartmann* (1909) has pointed out that fertilization is characterized more by the copulation of the cell nuclei than by the interaction of the cells themselves, and that, therefore, besides "amphimixis" between different cells, "automixis," i. e., the copulation of various nuclei within the same cell, should be taken under consideration as an important mode of fertilization among protists. A copulation taking place between sister cells is called "pedogamy," and declared to be frequent among amoebae, bacilli, and lower algae. Long-continued vegetative reproduction is accepted as causing a gradual increase in differentiation among the cells and their nuclei, and therefore the fertilization is viewed as a means of reestablishing the inner equilibrium, and thereby stimulating anew vegetative growth and multiplication. The effect exerted by amphimixis upon the variability of lower organisms has been discussed by *Pringsheim* (1910, pp. 120–126).

Of special interest are the following sentences, written by *Barker* (1901) in his first paper on Zygosaccharomyces, whose mode of conjugation is duplicated in a striking manner by the behavior of the large bacilli in their conjunct stage. The yeast cells, obtained from commercial ginger, produced beaks which touched each other with their tips, causing a fusion of the cells:

> The appearance of the compound cells, thus formed, was that of two ordinary cells attached to one another by an elongated neck with complete communication of their cavities through the neck, and at this stage with protoplasm filling up the whole of the cells and the neck.

A few hours later the formation of bright granules and of spores in both cells became noticeable. Sometimes the tubes did not conjugate, but turned into buds or branches. Satisfactory results concerning the behavior of the nuclei were not obtainable, but the author is inclined to accept the process as a sexual one, not merely as a fusion of cells, and he continues:

> There is one aspect of all simple sexual acts that appears worthy of further attention, and which is suggested very definitely by the present case. It would appear that whenever nucleated spore-producing protoplasm is being stored in neighboring cells, or whenever it has been accumulated and is parted by a septum, a strong tendency exists for union. Numerous examples can be given, such as the fusion of sporidia of Ustilagineae or of Protomyces, the nuclear fusions in teleutospores, aecidiospores, etc., or those in the ascogenous cells of Erysipheae, Exoascus, Peziza, etc., and in the basidia of Hymenomycetes, also the fusion of sister cells in some Conjugatae, e. g., Spirogyra.

Many additional data concerning the copulation of yeasts have been secured by *Guilliermond* (1910*b*—1912), who found the process rather widespread among the spore-forming yeasts and Schizosaccharomycetes; spores, too, sometimes showed fusion, occasionally already while still within the ascus. But numerous cells produced spores without previous copulation. Colonies of *Debaryomyces globosus* exhibited clearly the copulation occurring between sister cells. Often the two cells were quite different in appearance, "mais on ne saurait voir dans cette inégalité l'indice d'une tendance a l'hétérogamie." Other species, however, especially a *Zygosccharomyces Chevalieri*, furnished good examples of true heterogamic copulation; the whole content of a smaller cell (microgamet) passes over into a larger one (macrogamet), which transforms itself into an ascus.

According to *Marchand* (1912) the copulation of the spores by making beaks and bridges is fairly frequent with yeasts, though a great number of them germinate and develop independently.

That many parallels are presenting themselves between these observations and those enumerated above, relating to the behavior of the bacteria, is hardly to be denied. And this will become more evident when the following findings are also taken under consideration.

As early as in 1872 *Rindfleisch* pointed out that he often saw two bacteria united with each other, and that this union was not the result of fission. In 1875 *Klebs* reported in his V. contribution "Zur Kenntnis der pathogenen Schistomyceten" that motile rods often at first have the shape of short coccoid or oval bodies, and that these, after repeated touching and separating, at last enter a permanent conjunction, and then grow up into long rods and threads, which later segment themselves again into round cells. He calls the process explicitly "einen Act der Verschmelzung oder der Copulation."

Still more important is the following discovery, published by *Albrecht* in 1881. The cells of *Spirochaeta Obermeieri* were seen, when kept in blood at 37° C., to touch each other first with

their ends and then fuse together more or less completely, so that they presented the appearance of one organism. After a shorter or longer interval they separated again; but the author emphasizes that a true fusion is characteristic for this occurrence, which should not be mistaken for a casual apposition of two cells.

Buchner (1882) declared the occurrence of rods in V form to be characteristic of *B. subtilis*, while it was pointed out by *Escherich* (1894) that the long forms of the diphtheria bacillus are often to be found in V form or in rosettes, and that the ends touching each other are often broader than the rods themselves. *Kurth* (1898) and others have obtained analogous results with this species. Upon the behavior of the so-called *Vibrio denitrificans*, *Severin* (1897, p. 512) reported as follows:

In 1–2 tägigen Bouillonkulturen kann man häufig Stäbchen beobachten, die in sehr verschiedenartiger Vereinigung miteinander verbunden sind, bald zu zwei, bald zu drei, zuweilen noch mehr, bald in form von T, bald legt sich das eine Stäbchen an ein anderes in form eines Zweiges an, oder es vereinigen sich zwei derselben mit ihren Enden.

Under the title "An unusual bacterialg rouping" *Hefferan* (1912) discussed the various modes of rosette formation, as found by her with *B. rosaceus metalloides*. She is inclined to connect it with a peculiar mode of cell division, but the experimental support furnished for this assumption can hardly be accepted as convincing. The author herself explicitly admits that—

there remain numerous possibilities, yet untouched by investigation, as to the actual cause of this peculiar phenomenon, which I am inclined to believe is a problem closely related to the vital processes of the organism.

It was also noticed that not infrequently rods were swarming together to angles or to a rosette-like position, and that they then were either staying or again swarming away; "a peculiar clear space at the center" became often visible in this case.

One of our photographs of *B. radiobacter* (*Löhnis*) and *Smith*, 1916 *b*, original fig. 29) illustrating this mode of star formation has been reproduced as figure 277 on Plate XXII. A comparison with figure 274 on the same plate, showing the star formation from the symplasm, will be helpful for accurately distinguishing between both processes.

Apposition of motile cells in a T position to other cells has been further recorded by *Bajardi* (1902, with *V. lingualis*), who being evidently not acquainted with the analogous findings published before, wrote upon this fact:

Man findet hier die eigentümliche Erscheinung, dass häufig kürzere Stäbchen oder Fadenstücke sich rechtwinklig an die längeren Fäden anlegen, woraus man den Eindruck einer seitlichen Knospung gewinnen könnte.

Cytological investigations led *Rayman* and *Kruis* (1904) to the belief that copulation between young bacterial cells is by no means infrequent. And results obtained in ultramicroscopic studies induced *Gaidukov* (1906) to make an analogous statement.

Obviously without knowledge of *Albrecht's* early work, the conjunction shown by spirochaets has been repeatedly discussed during the last 10 years, and several authors have declared themselves to be inclined to interpret this process, whose last phase was often mistaken for longitudinal fission, as genuine copulation. See, for instance, *Sobernheim* (1907, p. 582), *Breinl* (1907), *Schellack* (1907), *Meirowsky* (1914 *b*), and *F. Levy* (1916). Especially the last-named author's dark field studies, made with *Spirochaeta Obermeieri*, are in complete agreement with those findings recorded by *Albrecht* 35 years before.

When studying the development of bacterial colonies *Graham-Smith* (1910) found that always a characteristic "post-fission movement" was noticeable, such as had been discovered by *Hill* (1902 *a*) with *B. diphtheriae*, indicating a decided tendency of the newly formed rods to place themselves parallel each other. This was realized either by "loop forming" (seen with *B. anthracis*), by "folding" (bacilli related to Anthrax, and *B. pestis*), by "snapping" (*B. diphtheriae*) or by slipping (*B. coli, pneumoniae, pyocyaneus, pseudo-tuberculosis, subtilis*, various vibrios and spirilla). The physiological meaning of this parallel arrangement has not been considered by the author; it seems, however, as if in well-made contact preparates of bacterial colonies always numerous cells are to be found in the characteristic conjunct stage, being connected by bridges or by beaks, such as are visible in figures 279–283, and especially in figures 289 and 291.

According to some observations made by *Faber* (1912) with *B. rubiacearum* pairs of rods in parallel arrangement may turn themselves by double folding into a cross-like position. This occurrence is similar to that described by *Hefferan*.

That the various modes of conjunction may be followed by the formation of lateral and of terminal regenerative bodies has been noticed by several authors.

Some of the drawings made by *Hueppe* (1885) of what he called arthrospore formation of *V. cholerae* (see fig. 49 on Pl. M) leave hardly any doubt that it is more correct to assume that the long spirilla in the characteristic V position, which later produce the round bodies at their ends, were in conjunction, than to accept this as a prefission phase. Similarly, *Babes* (1889) pointed out that the round regenerative bodies frequently seen by him with spirilla and vibrios are either located at one end of the cell or at the point where two cells touched each other, or, as he thinks, were they divided. The photograph of *V. cholerae*, made by *Friedrich* (1892) and reproduced as figure 140 on Plate XI, demonstrates especially clearly the appearance of conjunct cells and their relation to the formation of regenerative bodies.

The sexual processes ascribed by *Vincentini* (1893) to his so-called *Leptothrix racemosa* are probably to be interpreted as an example of conjunction, resulting in the production of round regenerative bodies. But the short abstract of the apparently rather confused paper, which was only accessible to me, allows no definite conclusion.

The very interesting drawings of regenerative bodies produced by acetic acid bacteria in 2-days-old cultures, made by *Henneberg* (1898) and reproduced as figure 57 on Plate N, represent the first clear indication that the formation of this type of bacterial reproductive organs is, indeed, very much alike to the zygospore- or to the ascus-formation of certain fungi. For instance, a picture of *Eremascus fertilis* published by *Guilliermond* (1910*b*) could be readily mistaken for a drawing of conjunct lactobacilli producing a lateral round regenerative body; even the septa visible within the mycelium find their counterparts in *Henneberg's* sketch. The following remark made by *Guilliermond* fits both cases equally well:

> L'anastomose s'accompagne d'une résorption de la parois séparatrice des deux articles réunis et permet la mélange de leur contenu dans la cellule mère de l'asque.

A photograph made by *Maassen* (1899) of his *Bact. esterificans Stralauense*, reproduced as figure 290 on Plate XXIII, exhibits, besides other interesting details, in the middle of its upper edge an exceptionally good example of the initial step leading to the formation of a lateral regenerative body, which should be compared with the upper part of *Henneberg's* drawing. *Tissier* (1900) found the ends of his *B. bifidus* often inflated, especially those connecting two united rods; and at this junction frequently a round regenerative body ("une boule") became visible. Analogous observations were made by *Fuhrmann* (1906) with 2-days-old cultures of his *Pseudomonas cerevisiae*. Rods with terminal inflations were seen to touch each other sideways, and a connecting bridge was found to exist between these bulbs. *Fuhrmann* says:

> Diese ganze Erscheinung erinnert sehr lebhaft an Bilder, wie wir sie bei der Zygosporenbildung zu sehen gewohnt sind.

Droba (1901) reported that he discovered "Zygo- and stylospores" with *Bac. tuberculosis*, and *Mühlens* and *Hartmann* (1906) thought that the round bodies which they found with spirochaets might be the products of some preceding act of fertilization. Some drawings made by *Prowazek* (1906*a*), reproduced as figure 89 on Plate S (from original figs. 10 *c*, 11*a* and *b* on Pl. II), illustrate very clearly how two separate regenerative bodies or one compound body (of the character of a zygospore) may be formed by two conjunct cells of *Spirochaeta gallinarum*, very much as it was seen and drawn by *Hueppe* (with *V. cholerae*) and by *Henneberg* (with *Bact. oxydans*). *White* and *Avery* (1909) noticed also quite correctly that the oval or kidney-shaped "nodules" of lactobacilli are located either at the point where two bacteria touched each other, or that each of them is supported by a short stem, branching out of the side of a rod. It was, however, far from being correct when they asserted:

> Their formation may undoubtedly be considered a true plasmolysis.

The photograph of *B. subtilis*, published in *Hiss* and *Zinsser's* textbook (1914, original fig. 125), which contains those cells in the characteristic conjunct position, which were reproduced

in figures 292 and 293 on Plate XXIII, also presents at the same time a well-developed lateral regenerative body, visible in figure 150 on Plate XI. A photograph of *B. coli*, made by *Kellerman* and *Scales* (1916), which was shown as figure 185 on Plate XV, is of still greater interest. With most cells the conjunction is easily noticeable, and a pair in V position in the upper part of the field shows again the regenerative body being formed at the touching point. *Almquist's* pictures (especially figs. 135, 138, and 139 on Pl. XI) offer some additional confirmative data, relating to *B. typhi* and *V. cholerae*, as does figure 172 on Plate XII (a reproduction of one of our photographs of *B. bulgaricus*).

The formation of endospores has been connected with copulation, probably for the first time, by *Hueppe* (1891, p. 29), who wrote:

> Die Endosporenbildung erscheint mir als wirkliche Fruktifikation, als einfachste Form einer Art geschlechtlicher Fortpflanzung, der Copulation, zur besseren Anpassung an die Art bedrohenden Aussenbedingungen.

This view was shared by *Gamaleia* (1900, p. 23); and on account of cytological results obtained with the large new species *B. Buetschlii* and *sporonema*, *Schaudinn* (1902) promoted the theory that the endospores represent the result of autogamy between neighbored cells, a theory which later has been confirmed by *Růžička* (1910), but contested by *Dobell* (1909–1911) and by *Swellengrebel* (1913). Investigations carried out by *Baur* (1905) upon the formation of arthrospores (or microcysts?) by Myxococcus led to results which are in several directions similar to those of *Schaudinn*, and the same holds true with regard to observations recorded by *Gross* (1913) concerning the arthrospore formation of spirochaets. *Park* and *Williams* (1914, p. 38), too, are inclined to interpret as "a primitive sexual process, a sort of autogamy" the fusion of metachromatic granules, which was seen to precede cell fission in the large, often branched, cells of diphtheria bacilli.

Another mode of interaction between separate bacterial cells has been described by *Vuillemin* (1888) in his studies upon the "zoospores" of the nodule organism from the legumi-

nous plants as follows:

> Parfois les zoospores se rapprochent et restent appliquées l'une à l'autre par le bout pointu . . . . Les boules brillantes sont souvent placées sur les faces opposées. Nous ne savons trop quelle interprétation attribuer à cette sorte de conjugaison. A un certain moment il y a, semble-t-il, une soudure véritable sans que le corps des conjoints subisse des modifications visbles.

After separation one body was seen to move rapidly away, while the other became immotile, increased in size and turned over into what seems to have been a gonidangium or a large round regenerative body. The French author concludes (l. c., p. 193):

> On se demande s'il n'y a pas là une sorte de fécondation, dont le resultat est de transformer la zoospore en spore.

Like *Vuillemin*, but apparently without knowledge of this author's findings, *Hartleb* (1900) was inclined to believe that the copulation of the "zoospores" of *B. radicicola* leads to the production of "zygospores."

That also a distinct sexual dimorphism may be found sometimes among the bacteria has been discussed for the first time by *Haberkorn* (1882), though it is not to be denied that his report does not look very trustworthy. Small bodies were seen to fuse with larger ones, which later developed to gonidangia (called "Samenkapseln" by *Haberkorn*). Essentially the same fact has been recorded by *Ferrán* (1885) in regard to the cholera vibrio. Small bodies, termed "antheridia," were seen to fertilize larger round "oogones," which afterwards became gonidangia. The Spanish author, who was hardly acquainted with *Haberkorn's* short communication in the "Botanische Centralblatt," points out that he found similar "oospheres" also with several bacilli. But his results differed in many respects so widely from those of *R. Koch* and his pupils, which then were accepted everywhere as the only reliable ones, that they probably would have been passed practically unnoticed, also if they had not been mixed with several quite unwarranted hypotheses, which were bound to create considerable distrust in *Ferrán's* whole work (cf. our discussion of his publication on p. 69). *Dowdeswell* (1889–1890), however, has fully confirmed *Ferrán's* discovery. Observations of the cholera organism in Ranvier's moist chamber showed him that, indeed, large round "oospores" are fertilized by small pear-shaped "zoospores," and that they afterwards break up into "sporules."

Firtsch (1888), on the other hand, who also paid attention to the large globules produced by *Vibrio proteus*, is of the opinion that they are simply the result of a fusion of the loops, frequently formed by the curved cells especially during the second day; despite the complete absence of thorough investigations in this direction, he feels justified to state:

Mit Fruktifikation haben diese Gebilde . . . natürlich nicht das Geringste zu tun.

Sexual dimorphism among spirochaets has been repeatedly discussed by protozoologists. For instance, *Perrin* (1906) interpreted the conjunction of thinner and thicker cells of *Spirochaeta Balbianii* as "conjugation of male and female gametes." *Prowazek* (1907 a), *Krzysztalowicz* and *Siedlecki* (1908), *Gonder* (1909), and others have shared this view, while it has been refuted by *Fantham* (1908), *Doflein* (1909, p. 315), *Dobell* (1912), and others.

A process of fertilization, very much like that described by *Ferrán* and *Dowdeswell* with *V. cholerae*, has been reported by *McDonagh* (1912) with *Spirochaeta pallida*. A round "macrogamete" was seen to be fertilized by a "microgamete," showing the typical form of a spirochaete, and afterwards to develop to a "zygote," which at first divided into four "sporoblasts" and later into numerous "sporozoites."

An unbiased consideration of all these more or less incoherent findings and opinions, collected on the foregoing pages, makes it undoubtedly imperative to abandon the a priori negative standpoint at present en vogue in regard to sexualism among the bacteria. It is readily to be admitted that a great deal of what has thus far been recorded upon this problem is rather unsatisfactory. But enough data remain which clearly indicate that more thorough investigations will yield important results.

Besides the normal mode of conjunction, which is practically constantly noticeable in all young cultures, especially from the second to the fourth day, I myself have seen occasionally, when examining the living material in the hanging drop, that two cells of about equal size unite themselves permanently in such a manner as has been described by *Klebs* (1875 a), and I have also occasionally met single large cells of *B. azotobacter* and of other species, which were attacked again and again by small motile bodies, exactly as it has been reported by *Haberkorn* (1882), *Ferrán* (1885), *Dowdeswell* (1889–1890), and by *McDonagh* (1912). Not knowing of any of these publications when these casual observations were made, they have not yet been followed up by special studies, but they may be mentioned here, because they perhaps will help to direct the attention of other investigators to this difficult subject.

More light upon this phase of the life cycles of the bacteria may be expected from careful researches upon the formation and behavior of the bacterial gonidangia, which at the same time will do away with much useless talk about "involution forms." A peculiar ring formation has been described by *Van Tieghem* (1884, p. 110) with *B. amylobacter*, by *Firtsch* (1888) with *V. proteus*, by *Morck* (1891) with *B. radicicola*, by *Schmorl* (1891) with *Streptothrix cuniculi*, by *Burri* (1897) with *B. bernensis*, by *Moro* (1900) with *B. acidophilus*, by *Rosenfeld* (1901) with several members of the *B. septicaemiae* group, by *Stefansky* (1902) with his *B. pyogenes ramosum*, by *P. Ernst* (1902) with *B. fluorescens*, and by numerous authors with various spirochaets. Several of these reports seem to indicate that these rings or loops are much inclined to turn into globules, as was already observed by *Perty* (1852), *Firtsch* (1888), *Morck* (1891), and by *P. Ernst* (1902), and it is not impossible that these globules are able to act later as the "macrogametes" of *McDonagh* and his earlier colleagues before developing to gonidangia.

Whether the conjunction of the young bacterial cells has anything to do with the appearance of the gonidia within these cells, remains to be seen. That, however, the round lateral and terminal regenerative bodies are frequently true zygospores becomes increasingly probable, though it is quite possible that, as with certain fungi, so also with the bacteria, "azygospores" may sometimes take the place of zygospores.

The peculiar triangular forms found with spirilla and other bacteria whose center gradually assumes globular shape while the ends are fading away (see figs. 86 and 87 on Pl. VIII) present another problem which perhaps will find its solution when attacked from this new point of vantage.

How far the formation and germination of endospores is dependent on a previous act of autogamy or heterogamy will have to be decided by further research. Our figure 69 on Plate VI indicates fairly well that the formation of endo- as well as of exospores may be influenced by the conjunction of the parent cells, and the conjunction between the liberated endospores themselves, as visible in figure 284 on Plate XXII, should be accepted at present at least, as an interesting occurrence of unknown physiological value. It should be kept in mind in this connection that analogous facts are known from various fungi, and it seems to be especially suggestive that, for instance, the sporidia of Ustilagineae have been found by *De Bary* (1884, p. 192) to copulate before germinating when kept in a poor substrate (water), but that on a rich substrate they germinate without previous copulation.

It has been pointed out in Chapter III that sometimes endospores, like the bacterial cells themselves, may enter the symplastic stage before reproducing new cells, and it is quite probable that the results obtained by us in this direction have been partially due to our keeping the cultures usually in much less concentrated substrates than are generally used in bacteriological laboratories, substrates, however, which are very favorable to a long-continued development of the bacteria, as was exemplified by the data given on page 189. It is well known that transplantation of well-grown cultures into water exerts a stimulating influence upon the formation of reproductive organs. It also strengthens the tendency of the bacteria to enter the symplastic stage. And the same may hold true in regard to the conjunction of the bacteria, which despite our very incomplete knowledge can be looked upon, like the formation of the symplasm, as a means of placing the continuity of bacterial life upon a broader and safer basis than that afforded by a single cell.

That studies on the behavior of the nuclear material within the bacterial cells during and after conjunction are not very promising at the present time, is hardly to be denied, the difficulties in this case being so much greater than with the yeasts and other lower fungi. However, careful and patient research will undoubtedly secure more evidence that, as has been made probable by the more or less casual observations quoted above, sexual processes also play their rôle in the lives of the bacteria, just as they do in the lives of all other, lower as well as higher, organisms, and that, in this respect also, the bacteria are not those unnaturally rigid things which they were declared to be by the preconceived doctrine of constancy and simplicity, but that they again behave much more like other living beings and, therefore, deserve to be studied like these in all the vagaries which they exhibit in the course of their life cycles.

V. METHODS.

1. ad I: DIFFERENT CELL FORMS.

On pages 37–43 the main points of importance for studies upon pleomorphistic problems have been discussed. In addition, the following references occasionally may prove helpful in further investigations.

In regard to microscopic observations *R. Koch* (1881, p. 6) and *Fraenkel* (1891, p. 86–89) have published most valuable hints for avoiding possible errors due to artefacts, contaminated staining solutions, etc. Equally worth reading is *A. Fischer's* (1899, p. 30) discussion of the vexatious rôle played sometimes by peptones, albuminous, and other substances in dried preparates. For staining, the Congo red adsorption method, as worked out by *Benians*, is highly recommended by *Hort* (1917*a*). According to *Knack* (1915) nigrosin is superior to India ink, and especially suitable for studying living material. Many details concerning dried smears and hanging drop preparations are given in *Hueppe's* book on bacteriological methods (1891, pp. 48–51, 86–99). *Prazmowski* (1912, p. 110) found wax preferable to fat or vaseline for sealing hanging drops, because it does not shut off the air so completely as the last-named substances do. *Schouten* (1905) pointed out that hanging drops of broth often become too acid to allow further growth; placing some 2 per cent KOH below the drop is recommended as preventive measure. *Th. Cohn* (1913) found it useful to change the hanging drop into a thin liquid layer by placing a small cover glass on it, an arrangement which seems, indeed, to be very practical for certain purposes. The hanging agar block method of *Hill* (1902 *b*) gave *Baur* (1905) less satisfactory results than the hanging drop; *Graham-Smith* (1910), who used it extensively, had also to record frequent failures.

The continuous observation of bacterial development under the microscope is often impossible on account of the disinclination of many bacterial cells to grow under such abnormal conditions; moreover, their motility may spoil the result. On pages 38–39 it has been pointed out why the statement, made by some authors. that only those changes should be accepted as correctly ascertained, which have been observed directly and without interruption under the microscope, can not be considered as appropriate. Even *Winogradsky* (1888) had to admit that the movements of the bacterial cells often hindered the continuous observation, which he declared absolutely imperative for solving pleomorphistic problems. And though *DeBary* (1884, p. 137) was undoubtedly right when he said that the continuity of the different phases in the growth of fungi (and bacteria) must be as accurately ascertained as the fact that the apple is a developmental product of the apple tree, certainly neither he nor anybody else would insist that only if this apple has grown from its beginning to full maturity in the laboratory under prescribed conditions and under the never flinching eye of one observer the fact can be accepted as properly proven.

The use of single-cell cultures is another desideratum which is greatly exaggerated by some theorists. Repeated plating coupled with careful microscopic tests furnishes, as has been discussed on page 39, exactly the same results as the single-cell cultures, which generally are less satisfactory on account of lack of growth and greater chances for contamination. Occasionally the fishing methods recommended by *Schouten* (1905–1907), *Barber* (1907–1911), *Nieuwenhuis* (1911), and *Hecker* (1916) will be useful. Usually, however, the India ink method of *Burri* (1909) has much in its favor, especially in connection with the improvements worked out by *Viehoever* (1913, p. 241: dilutions to be made in small test tubes) and by *Troili-Petersson* (1904: droplets to be placed upon gelatin or agar on hollow slide or in Boettcher's chamber). The little-known drop plate method of *Holten* (1893) deserves also further testing.

After having made the dilutions in a good nutrient solution, small droplets are placed upon a glass plate possessing a net work of glass ridges (1 mm. high); another glass plate is put on as cover, and those drops containing only one cell can be marked and the growth studied directly under the microscope. The early method introduced into bacteriology by *Klebs* (1873) to keep the inoculated gelatin in a Geissler chamber, which allows the microscopic study of the isolated germs, offers other obvious advantages for investigations upon the life history of the bacteria. It has already been recommended by *H. M. Ward* (1895), who also made gelatin cultures on cover glasses.

Replacing the Petri dishes by flat square bottles tends further to reduce the possibilities of contamination; and often repeated plating, together with a sufficient number of parallel tests, whose great importance has been pointed out on page 39, makes the experiments as safe as, or even safer than the various modes of single-cell cultures, but generally much more successful.

Frequent transfers from and to the same substrate usually hinder the bacteria to display their natural pleomorphism. Therefore, if not such incomplete results are wanted for some special purpose, long-continued tests on a greater variety of substrates, kept at different temperatures and under otherwise modified conditions, are generally preferable, and they are indispensable if complete and correct data upon the life history of the bacteria are to be secured.

As a rule the substrates recommended for laboratory use are too concentrated, and the large amount of metabolic products accumulating therein often causes the premature death of the cultures, which in less concentrated media continue to exhibit their characteristic alternating mode of life at least for several months. Some recipes for such weak nutrient solutions, suited for soil bacteria, have been given in our first preliminary paper (*Löhnis* and *Smith*, 1916 *a*, pp. 686 and 689), and it was also mentioned there that sterilized soil itself proved to be a very suitable medium, allowing *B. azotobacter* to display all its characteristic cell forms with the greatest precision within a few weeks. "Rejuvenation" in sterilized soil has also been found by *Bredemann* (1909) to be very helpful for reestablishing the common character in many different Amylobacter strains. Cultivation in water has helped *Stamm* (1914) and others to discover important parts of the life cycles of *V. cholerae* and of other organisms, which are much less conspicuous on the standardized substrates. Broth diluted with water furnished *Ferrán* already in 1885 all the different cell forms of the cholera bacillus and gave later *Taddei* (1909) the various types of growth of *Streptoc. pyogenes*, *choreae*, and *erysipelatos*. *Distaso* (1916) recommended diluted serum (1 part serum diluted with 1 part tap water, and digested by trypsin or pancreas).

Increased aeration, which is often desirable when working with solutions can be established either by immersing plates or strips of gypsum partially into the liquid, as has been done with good results, for instance, by *Casagrandi* (1901) and by *Cacace* (1903), or simply by adding a strip of filter paper before sterilizing, so that it stands out about an inch above the solution. Increased atmospheric pressure, together with relatively high temperature, was found by *Arloing* (1908) to be very effective in bringing about the development of clubbed, branched, and of giant forms of *B. tuberculosis*. On the other hand, anaerobiosis allowed *Concetti* (1901) to change the actinomycotic type of growth of *B. diphtheriae* quickly back into the typical, highly virulent rod form, and *Almquist* obtained many of his interesting results with *B. typhosus*, *V. cholerae*, and with other pathogenic organisms by keeping his cultures at temperatures as low as 10–12° C.

The influence of a wider range in acid and alkaline reaction of the substrates deserves to be made the object of detailed studies. Already in 1888 *Wasserzug* noticed that *B. prodigiosus* always produced rods and threads in acid, but coccoid and spiral forms in alkaline broth. *Th. Smith* (1890) saw *B. mallei* grow with a yellow-orange color on acid, but as a gray layer on alkaline substrates. According to *Thiercelin* and *Jouhaud* (1903 *b*) the Enterococcus appears as a typical Streptococcus in slightly acid broth, but alkaline reaction stimulates the development of tetrades. Anaerobic bacilli were more ready to produce their "giant" forms in *Hibler's* (1908) experiments when 1–2 per cent Na_2CO_3 was added to agar, serum, or potato. On the other

hand, *B. typhosus, coli,* and related forms presented their wide pleomorphism to *Hort* (1917 *a*), when kept in distinctly acid broth (usually +10 to +20, sometimes up to +60 phenolphthalein). *Bunker* (1917) noticed that varying hydrogen-ion concentration induced the appearance of all different types of diptheria bacteria desscribed by *Wesbrook.*

For special purposes, especially for securing a quicker development of the various forms, it will sometimes become advisable to increase the amount of certain substances in the substrates, though under such conditions special care must be taken to prevent an early death of the culture. *Albrecht* and *Ghon* (1900), for instance, pointed out that the addition of 5 per cent glycerin or 5 per cent sugar proved to be very useful for studying the pleomorphism of *B. pestis.* And it was with the same organism that *Hankin* and *Leumann* (1897) first found out the stimulating influence exerted by a higher concentration ($2\frac{1}{2}$–3 per cent) of common salt. Analogous results with this and numerous other species have been recorded by *Matzuschita* (1900), *Skschivan* (1900) *Rosenfeld* (1901), *Stefansky* (1902), *Maassen* (1904), *Hata* (1908), and others. That most of the cell forms seen by these authors have been wrongly classed as involution forms and that common salt merely speeds up the normal development and induces often, on account of its physiologically drying effect, the production of resting and reproductive organs has been discussed in Chapters I and II.

Other salts, like the lithium compounds tested by *Gamaleia* (1900, p. 207), the rubidium, caesium, magnesium, strontium, baryum chlorides used by *Maassen* (1904), potassium iodide and urea tested by *Péju* and *Rajat* (1906–1907), and by *Wilson* (1907), exert, besides their general osmotic action, more or less specific influences. And this is still more the case with the various antiseptics, such as 0.5 per cent potassium bichromate (*Thiercelin,* 1903), 0.5–1.5 per cent carbolic acid (*Cacace,* 1903), 0.2 per cent saturated alcoholic solution of methyl violet (*Walker* and *Murray,* 1904), or small amounts of $CuSO_4$ (*Garbowski,* 1907*b*).

Special substrates have been used and recommended in many cases, so for developing the branched forms of *B. radicicola* by *Stutzer* (1900–1901), *Hiltner* and *Störmer* (1903), *Buchanan* (1909), *Zipfel* (1911), and many others, for *B. diphtheriae* by *Escherich* (1894, p. 81), *Abbott* and *Gildersleeve* (1903), for *B. tuberculosis* by *Wolbach* and *Ernst* (1903) and by *Wherry* (1913). Egg substrates proved to be of special benefit in investigations upon branching made by *Fraenkel* (1895), *Meyerhof* (1898), *Dorset* (1901 *b*), and *Kodama* (1908), while serum was found to be most useful by *Kohlbrugge* (1901, for water vibrios), by *Vincent* (1902 for branching streptococci) and by *Carpano* (1913 for developing the full pleomorphism of *B. mallei*); continued cultivation of *B. coli* in ascitic fluid enabled *M. E. Abbott* (1900) to fix the coccoid growth, so that it did not revert to the rod form. It goes without saying that the skillful use of many varied substrates, together with such an arrangement of the experiments that the bacteria are allowed to grow under conditions as natural as possible, will lead to the most satisfactory results.

As has been pointed out in Chapter I, the study of symbiotic effects is also of very great importance. Instead of keeping different strains in mixed cultures, as was already done with good result by *DeBary* (1884, p. 503), it may be sometimes preferable to adopt the "double test tube" method of *Smirnow* (1908, the apertures of the smaller inner tube being covered by celloidin), or to add merely the sterilized metabolic products of other cultures, a method which has given remarkably good effects, even when the material was taken from old gelatin cultures of the same species (*B. mycoides,* according to *Nadson* and *Adamovič,* 1910).

2. ad II: REPRODUCTIVE ORGANS.

It has been discussed in Chapter II, especially on pages 108–119, that numerous difficulties may arise in the course of investigations upon the formation and the further behavior of the various types of reproductive organs of the bacteria, and that generally their characteristic function, viz., the reproduction of new vegetative cells, will have to be studied directly, to eliminate all doubtful points, which can not be definitely settled otherwise. It must be borne in mind, however, that the conditions usually prevailing in the hanging drop or agar block preparations are often not favorable to the development of new cells, and that, therefore, a few negative results obtained in this manner can not be accepted as a safe basis, on which to found final

conclusions as to the reproductive or nonreproductive character of some problematical body. It needs hardly to be emphasized that especially the study of the small gonidia, as well as that of the more conspicuous regenerative bodies, necessitates great care in making microscopic examinations. When discussing *A. Fischer's* much exaggerated plasmoptysis hypothesis, it has been pointed out that a very thorough cleaning of the slides and cover glasses (by potassium bichromate+sulphuric acid) is absolutely necessary. Great care in making and fixing smears is equally essential, as many of these frail things will not stand the ordinary rubbing and heating; the round regenerative bodies are especially liable to be materially altered by excessive heat. Lack of care in rinsing the stained preparate may wash away many of the slightly fixed bodies.

More than ordinary cleanliness is also essential for cultural experiments. Sterilization of vessels and substrates kills the regenerative bodies more easily than the endospores, but they still may become visible in the microscopic field and cause considerable error. As figure 295 on Plate XXIII a photograph has been reproduced (*Löhnis* and *Smith*, 1916 *b*, original fig. 57), showing various vegetative cells and regenerative bodies of *B. Azotobacter* developing from the symplastic stage, and in figure 296 (reproduced from original fig. 58, l.c.) the same material is demonstrated after it had been heated for 30 minutes in the autoclav at 20 pounds pressure. It is evident that substances and vessels, containing such bodies, are very liable to lead to erroneous results. Careful comparative studies of steril controls will always be advisable, and occasionally the treatment of the glassware with chromic acid and the filtration of the substrates through Berkefeld, Chamberland or asbestos filter (*Heim*, 1906, p. 35) will become necessary.

Transplanting vigorously growing cultures of several days age into water, mineral solutions, on substrates containing a relatively high amount of salt, or keeping them at comparatively low temperatures, are the means which have been used most successfully to stimulate the development of reproductive organs. Transfers made into water gave *Van Tieghem* (1879 *b*) very satisfactory results in his studies upon the spore formation of the bacteria, including the arthrospores of spirochaets. In the same way *Braem* (1889) got many different types of reproductive organs (regenerative bodies, gonidangia, etc.), which he mistook for signs of "degeneration," and *Rullmann* (1900) recorded analogous findings in mineral solutions as being "Hungerformen". Many of the "abnormal" cell forms appearing on salt substrates leave no doubt about their being regenerative bodies or gonidangia, though they, too, were usually classed as "involution forms." Especially the investigations made in this direction by *Matzuschita* (1900) and by *Maassen* (1904) have furnished numerous data, which may be used as a basis for further, more thorough research. *Almquist* (1904), *Fuhrmann* (1906), and *Hammerl* (1906) ascertained that these various forms, whose development is favored by increased salt content of the substrate, are indeed reproductive organs. The first-named author (*Almquist*, 1904–1916) has also contributed much material illustrating the stimulating effect of low temperatures (10–15° C.) upon the production of regenerative bodies, especially by pathogenic organisms. Results secured by *Schürmayer* (1900) and by *Arloing* (1908) in regard to the formation and multiplication of gonidia, regenerative bodies, and of gonidangia of the tuberculosis group are in good agreement with *Almquist's* observations.

Change in reaction naturally will also exert its influence. *Garbowski* (1907*b*), for instance, noticed in the course of his studies upon variability and spore formation of *B. luteus sporogenes* that on nitrate agar endospores were readily produced, while on sugar or glycerin-ammontartrate agar only darkly staining inflations became visible (either regenerative bodies or gonidangia), and that this difference was due to an alkaline reaction developing in the nitrate agar and an acid one in the glycerin or sugar agar. *Bredemann* (1909) has collected more evidence in regard to the favorable influence of an alkaline reaction upon spore formation. On the other hand, it seems equally advisable to study more closely the specific effect of a more or less acid reaction upon the production of the other types of reproductive organs.

Simonds (1915) has pointed out that besides composition and reaction of the media the influence of symbiosis should not be overlooked. Experiments with the double test-tube

method (see p. 207), or the use of substrates containing the metabolic products of the same or of another species, seem to be very recommendable also in this case.

Increased or decreased aeration may be equally helpful. *Archangelski* (1883), e. g., found that the small round reproductive organs (gonidia and regenerative bodies) of *B. anthracis* multiplied readily as such in absence of air, but reproduced promptly rods in presence of air. *Bredemann* (1909), on the other hand, had a constant aerobic culture of what he calls "microoidia" of the anaerobic *B. amylobacter*.

That the gonidia show much variation in their staining reaction has been emphasized in Chapter II. Often the common staining, especially with fuchsin, is applicable; sometimes, however, these bodies are very little inclined to take any stain at all. *Lugol's* solution has been found helpful in such cases by *Kuntze* (1904) and by *Růžička* (1908); but many authors give preference to one or the other kind of vital staining. Some valuable hints upon the principles of this method may be found in papers written upon this subject by *Pfeffer* (1886), *Campbell* (1888), *A. Fischel* (1903), and *Ph. Eisenberg* (1913, pp. 437–446). Methylene blue has been used as early as in 1885 by *Babes* in his studies upon the motile "granules," which he discovered in the cells of *V. cholerae*, and it has been equally preferred by *Zettnow* (1897), *Nakanishi* (1900 *a*, 1901), *P. Ernst* (1902), *Mencl* (1910), *Meirowsky* (1914 *b*), and others. *Amato* (1908) recommended "Brillantkresylblau," *Balfour* (1912), especially for blood preparates, toluidin blue, and *Prazmowski* (1912 p. 148) got most satisfactory results with a mixture of methylene green and fuchsin. Identical results were obtained by *Swellengrebel* (1906) when the vital staining was replaced by the Heidenhain method, applied to the dried preparate, fixed with 35 per cent formalin. And besides this, the various modifications of the Romanowsky-Giemsa method have been repeatedly found to be of special value for such studies, as may be seen from the publications of *Zettnow* (1899), *Feinberg* (1900), *Giemsa* (1904–1914), *Herzog* (1910), and of *Betegh* (1911), while *A. Meyer* (1912, p. 61) takes the opposite standpoint. That the cytological theories and the microchemical methods of the last-named author (l. c., pp. 209–247) have not met with general approval was mentioned in Chapter II (p. 113).

A special staining method for gonidia has been recommended by *Fedorowitsch* (1902). It is a modified Gram method and deserves further testing, as frequently the gonidia have shown positive reaction with this method, even if the parent cells themselves are Gram-negative. Occasionally one or the other of the various methods may become applicable which have been developed for staining the "granules" in diphtheria, tubercle, and leprosy organisms by *Lutz* (1886, p. 87), *Unna* (1887, pp. 12, 15), *A. Neisser* (1888, p. 175), *Spengler* (1907), *Betegh* (1908–1909), *Knoll* (1910), and *Fontes* (1910).

The dark field method, which *Meirowsky* (1914 *b*, p. 15) and others found to be very useful for such investigations, is not restricted to living preparates. Dried smears also often give very good pictures, as was pointed out recently by *Leishman* (1918), and as we have shown in the photograph reproduced as figure 234 on Plate XVIII (from *Löhnis* and *Smith*, 1916 *a*, original fig. 42).

Because the gonidia often, though not always, display a slightly but distinctly higher resistance than their parent cells against various deleterious influences, it is to be expected that more detailed investigations will also provide us with means to separate the gonidia from the vegetative cells. Observations made by *Fuhrmann* (1908) and others indicate, for instance, that a comparatively high concentration of NaCl is much less detrimental to the gonidia than to the cells, and the same seems to hold true in regard to a weak KOH solution, according to some findings by *Frank* (1890) and by *Jessen* and *Rabinowitsch* (1910).

As the ordinary laboratory substrates very seldom allow the direct upgrowth of isolated gonidia, the positive results obtained in many experiments upon so-called heterogenesis, where, in fact, dying or dead plasma of fungi and algae, not altered by heating, proved to be a very suitable medium for securing new upgrowth of bacteria from their gonidia, seem to promise equally good results for new methods to be developed along these lines. In addition to what has been said upon this subject on pages 148–150, it may be pointed out that especially

the algae experiments made by *Dunbar* (1907) and the blood tests of *Fokker* (1887, p. 72) deserve to be carefully studied anew. Autolyzed tissue (liver, kidney, brain, etc.) may be useful, too, in some cases; *Couret* and *Walker* (1913) obtained good growth of pure cultures of parasitic amobae on it.

When experimenting with the filterable part of the gonidia, still further difficulties are to be overcome. Faulty bougies or too long continued filtering under too high pressure are especially liable to cause incorrect results. *Doerr* (1911) and *Fontanel* (1913) have published valuable papers upon the technique, thus far developed, and its proper use. But especially in regard to securing a new development of normal bacterial cells from the filtered gonidia practically all remains to be done. However, results obtained by *Nocard* and *Roux* (1898), *Nocard* and *Leclainche* (1903–1905, Vol. I, p. 449), *Bordet* (1910), *Borrel* et al. (1910), *Almquist* (1911–1917), *Hort* (1917 *a*), and in our own experiments (*Löhnis* and *Smith*, 1916 *a*, p. 695), though still very incomplete, call for a more thorough study of these problems. That occasionally colloid granules may become a source of error was discussed by *Huntemüller* (1916) and by *Hallenberger* (1917).

Observations upon the formation and germination of the lateral and terminal round regenerative bodies and of arthrospores generally present no more difficulties than do analogous experiments with endospores. As soon as their increased resistance is more completely known, their separation from the vegetative cells by moderate heating or by thorough drying will become an easy task. Some data recorded by *Berestneff* (1907), *Rodella* (1908), and by *Almquist* (1916) are already quite satisfactory. Cultivation on serum favored sometimes distinctly the pure growth of round regenerative bodies (*E. Klein*, 1900; *E. de Negri*, 1916).

Because in stock cultures the endospore formation often shows a tendency to vanish more or less completely, repeated pasteurization may be used to prevent this change, as was recommended by *Beijerinck* (1901 *a*). To suppress the spore formation experimentally numerous methods are available. Often the use of small amounts of antiseptics, first tried successfully by *Roux* (1890), will give the best results; in other cases cultivation in milk (*Grassberger*, 1902), adding of eosin to the substrates (*Noguchi*, 1908), keeping the cultures at nearly maximal temperatures (*Ph. Eisenberg*, 1914) or other means may be preferable.

For the regeneration of endospore formation *C. Phisalix* (1892) found the cultivation in blood most successful with *B. anthracis*, while *Grassberger* (1905) and *Grassberger* and *Schattenfroh* (1907) saw best results with their anaerobic butyric acid bacilli when sugar was added to the substrates. As the regeneration of a lost spore formation is fundamentally not very different from the new development of this faculty in a strain (or so-called species) which thus far has appeared as being entirely and constantly asporogenous, the same method which promises the best results in the latter case, viz. a careful study and repeated heating of the intermediate stages between regenerative bodies or gonidangia and endospores developing from the symplasm will also undoubtedly in many cases secure quicker and always less haphazard results than the methods first mentioned.

3. ad III: SYMPLASM.

For obtaining well developed bacterial "plasmodia" *W. Winkler* (1899) found it most useful to place pieces of raw meat or potato into sour beer-wort, slightly acid bouillon, or a decoction of mushrooms. After 24–36 hours the "plasmodia" were seen to grow forth and soon after they began to form bacterial cells, which later separated themselves. On page 169 it has been mentioned that *Klebs* (1883 *b*) has directly observed under the microscope how the symplastic masses of the tubercle bacilli sprouted out from cuts of tubercular tissue kept in a well aerated chamber. In most cases it is by no means difficult to find out by daily testing of cultures one to several weeks old when the formation of the symplasm reaches its maximum and the regeneration of new cells begins to take place, provided that the points mentioned on page 206, concerning suitable cultural conditions have not been overlooked.

Transfer of small amounts of the symplasm in the common manner, or after picking out single flakes or clumps with one or the other of the various single-cell methods (discussed on

page 205, will occasionally give more conclusive results than the continued study of the material, kept in the old substrate.

Observations made with the unstained living material in the hanging drop have usually not given satisfactory results in the cases where I have employed this method. The irregular surface and density of these clumps and flakes causes nearly always such abnormalities in refraction and reflection of the light that the new formation of bacterial cells could not be accurately followed in this way. Movements within the slimy masses increase these difficulties. On the other hand the possibility can not be denied that occasionally good results will be secured. *Růžička* (1903), for instance, seems to have been more successful with this method.

Small flakes of symplasm, especially those formed by filterable gonidia, give very good pictures in the dark field; but, as was pointed out by *Leishman* (1918), the strong light seems to check all further development. Possibly some mode of vital staining will help to overcome the difficulties standing in the way of studying the living material.

However, the photographs reproduced on Plates XVIII to XXI will prove sufficiently, I believe, that stained preparations can furnish many interesting data, especially when they are made from the same culture in frequent intervals. That the staining qualities of the symplasms vary widely has been discussed on pages 182–183, and on page 178 it was pointed out that and why photomicrographs of such preparations are always rather inferior to the original. According to *Weigert* (1875) hematoxylin has proved to be most useful for staining bacterial "zoogloeas" within the tissue, but *Klebs* (1878) saw it act only upon the "granules" (the regenerative units) within the slime. *Herzog* (1913) found besides methylene blue, giving the metachromatic reaction, Giemsa solution best suited, which stains the regenerative units red, like the "eosinophilic" granules in leucocytes. It is not impossible that one or the other of the color reactions used for amyloid and hyalin substances, described by *Lubarsch* (1903), may also find application in investigations upon bacterial symplasm.

The comparatively high resistance of the symplasm against acids and alkali, which *W. Winkler* (1899) has made use of for separating bacterial "plasmodia" from surrounding bacterial cells, also allows, if necessary, a thorough cleaning of the fixed smear, especially the solving of precipitates, which otherwise might disturb the picture. Great care in rinsing, however, is essential, because, as *Fokker* (1882) has already noticed, the fixation of the symplasm by heat, as well as by alcohol, is sometimes very incomplete.

Certain substrates, especially those made up from meat, peptone, etc., may often present vexatious flakes and clumps, which react like genuine symplasm, but which are either coagula from the ingredients used, or, though real symplasm, do not belong to the cultures under experiment, but were produced by bacteria which have grown on the ingredients before they were used for making the substrates. As with the regenerative bodies to be found in many substrates, here also careful comparative tests of the steril media are indispensable. Figure 297 on Plate XXIII shows such a doubtful flake from sterile beef agar (*Löhnis* and *Smith*, 1916 *b*, original fig. 61). It looks exactly like some real symplasm, for instance, like that of *B. fluorescens*, whose transformation into pale oval cells was illustrated in figure 263 on Plate XXI. Figure 251 on Plate XX (symplasm of rods and spores of *B. azotobacter*) may serve as another object for comparison. Naturally, a final decision can be reached with such dead or "fake" symplasm only by carefully ascertaining whether or not it is able to produce new cells.

It is easily understood that transfers made at the same time from one culture, containing large amounts of symplasm, into various substrates which are to be kept under different conditions, will offer excellent opportunities for securing an accurate insight into the characteristic behavior of a species. Careful, repeated heating of the symplasm and of the regenerative bodies developing from it, has proved to be the most promising way for inducing experimentally sporulation in a strain, which had never formed endospores before. That a very good starting point for experiments on the effects due to symbiosis will be furnished by cultures containing the bacteria in their symplastic stage has been mentioned above (p. 188);

and it was pointed out, too, that long-continued observations upon the same culture (in parallel sets) will contribute much valuable material toward the solution of problems concerning the so-called involution forms, bacterial variation, mutation, etc.

4. ad IV: CONJUNCTION.

Hardly any special data are available at the present time as to the best manner of studying bacterial conjunction. Experiments with the living material at the right time (usually from the second to the fourth day) are most recommendable. Because the motility of the cells is often a rather disturbing factor, their incarceration into the meshwork of fine cuts of elder pith, as recommended by *Fuhrmann* (1908), may be tried. Contact preparates give often, as was shown by several of the photographs, much better pictures than do smears, wherein the fine connections are easily destroyed. If by such tests the right moment has been fixed, the study of the living material should be started. Occasionally vital staining may be helpful.

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PLATES A TO S AND I TO XXIII.

[N. B.—The page numbers in () refer to the pages where the illustrations have been discussed.]

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PLATE A.

FIG. 1 (p. 36).—Life cycle of *B. azotobacter*. The broken straight lines divide the different types of growth indicated by the letters A to M. The Greek letters α to λ refer to subdivisions. The single and double pointed arrows indicate the development of one form from another. The four circles confine, in every case, all those forms which represent together a rather constant mode of life, and which have been usually considered as bases for establishing separate species. *Löhnis* and *Smith* (1916 *a*, p. 678).

FIG. 2 (p. 45).—Morphological changes of *Micrococcus gonorrhoeae*. *Herzog* (1913, original fig. 6).

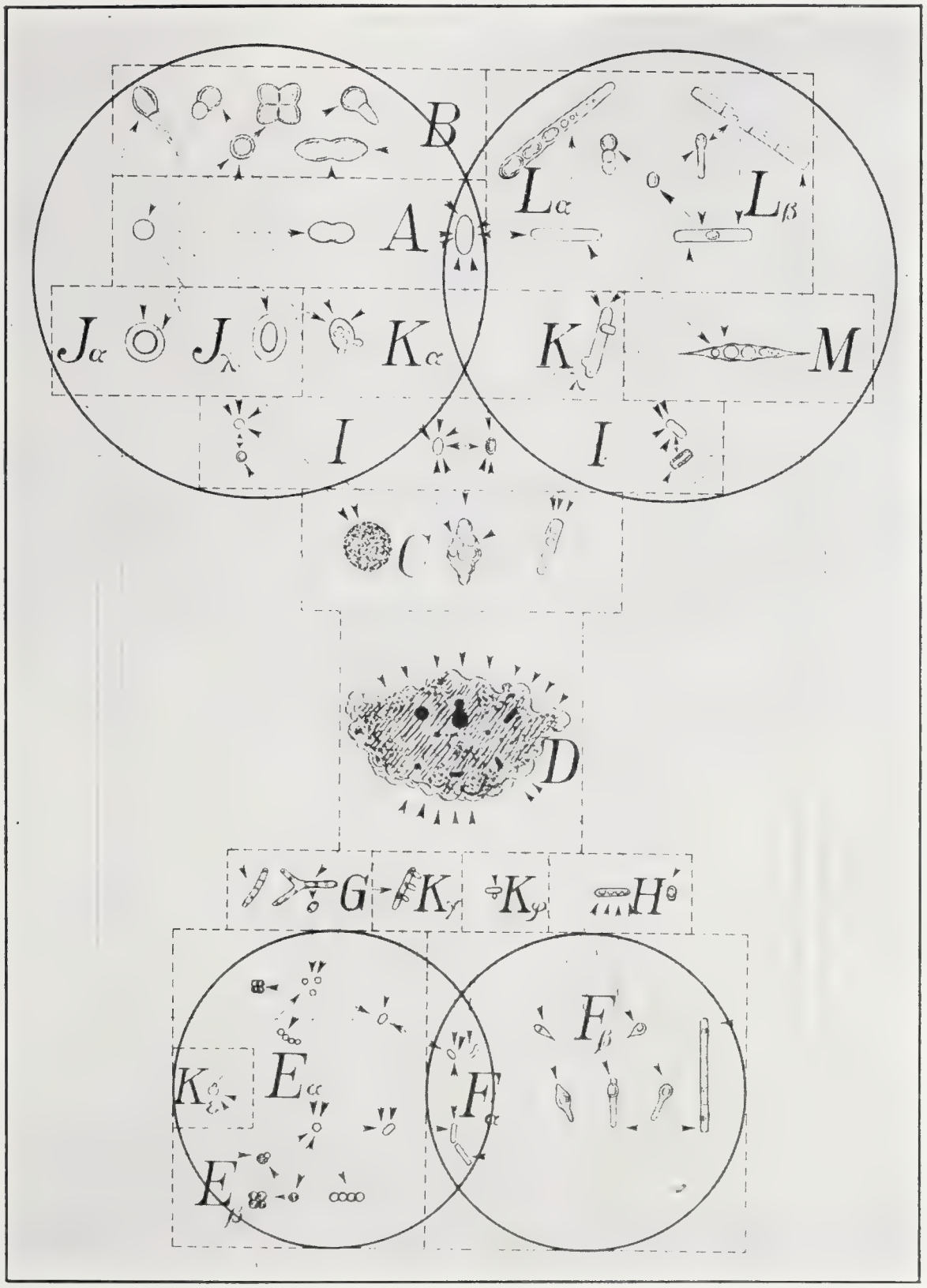

B
A
L_α
L_β
J_α
J_λ
K_α
K
M
I
I
C
D
G
K_γ
K_φ
H
K_ε
E_α
E_β
F_α
F_β

Fig. 1.

a
b
c
d
e
f
g
h
i

Fig. 2.

PLATE B.

FIG. 3 (p. 46).—Pleomorphism of streptococci. *Babes* (1895, original fig. 2). ×800.

4 (p. 47).—*Leuconostoc hominis Hlava* (1902, original figs. 3–6). ×1,000.

5 (p. 50).—Proteusartiger Luftbacillus. *Matzuschita* (1902, original figs. II–V). ×1,000.

Fig. 3.

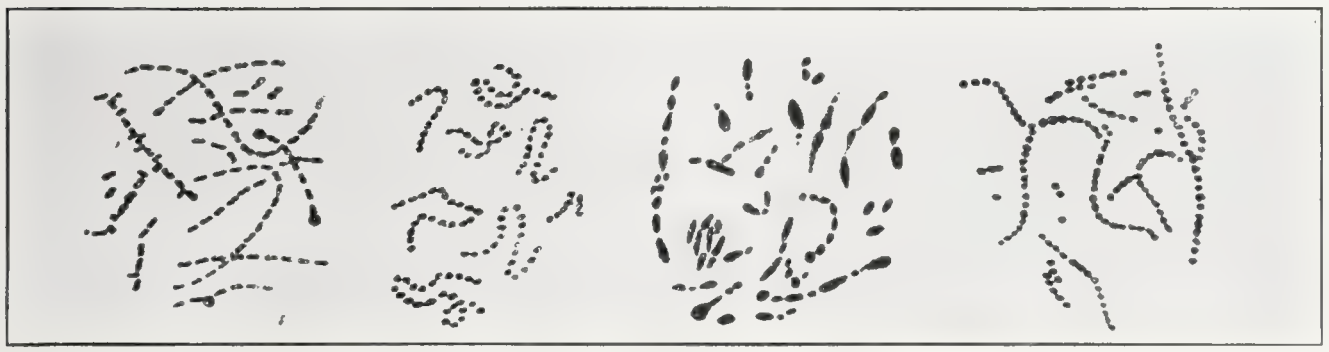


Fig. 4.

Fig. 5.

PLATE C.

FIG. 6 (p. 49).—*Urosarcina Hansenii Miquel* et *Cambier* (1902, original fig. 172) ×1,000.

7 (p. 50).—*Bacterium merismopedioides Zopf* (1883, original fig. 19). ×900.

8 (p. 50).—*B. bifidus communis Tissier* (1900, original figs. 4 and 6). Branching and "formes vésiculeuses". ×1,000.

9 (p. 52).—*B. funduliformis Hallé* (1898, original fig. 3). ×1,000.

10 (p. 52).—Anaerobic bacilli from meningitis. *Ghon*, *Mucha* and *Müller* (1906, original figs. 6, 20, and 9). ×1,000.

Fig. 6.

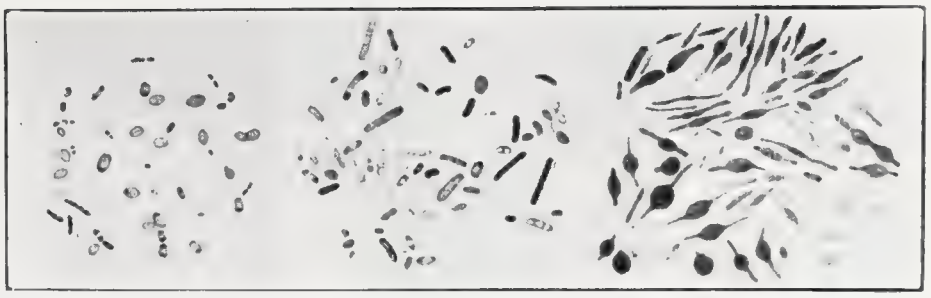


Fig. 10.

Fig. 8.

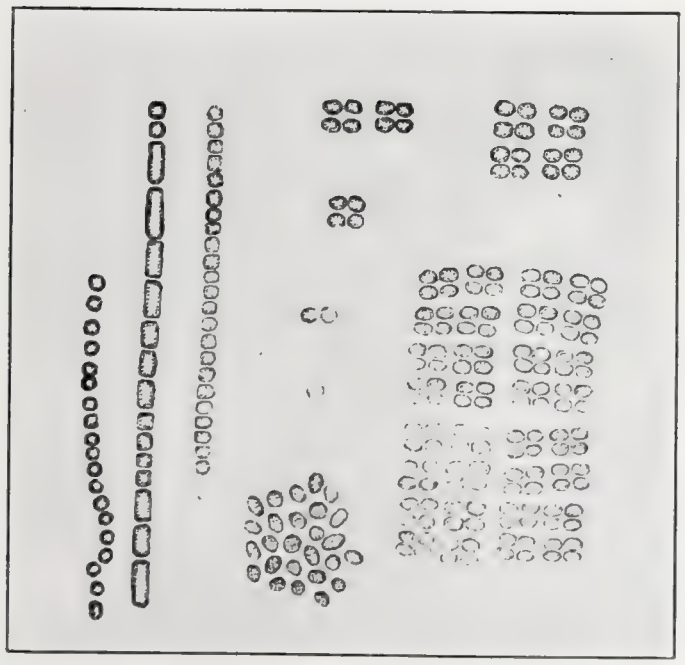


Fig. 7.

Fig. 9.

PLATE D.

FIG. 11 (p. 53).—*B. pestis.* *Albrecht* and *Ghon* (1900, original figs. II, 2-4; III, 5 and 9). ×1,000.

12 (p. 54).—*B. influenzae.* *Crookshank* (1896, original fig. 122, p. 249). ×1,200.

13 (p. 55).—*B. involutus* *Waelsch* (1905, original figs. 4 and 6). ×1,000.

14 (p. 55).—*Proteus hominis capsulatus* *Bordoni-Uffreduzzi* (1888 *b*, original fig. VII, 3). ×750.

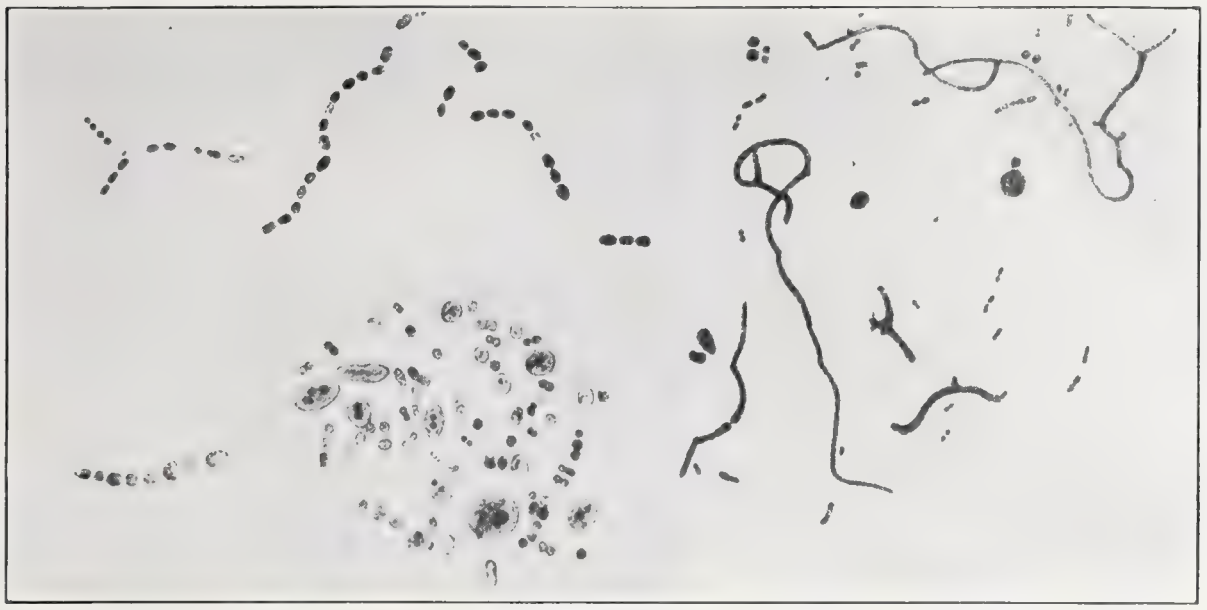


Fig. 11.

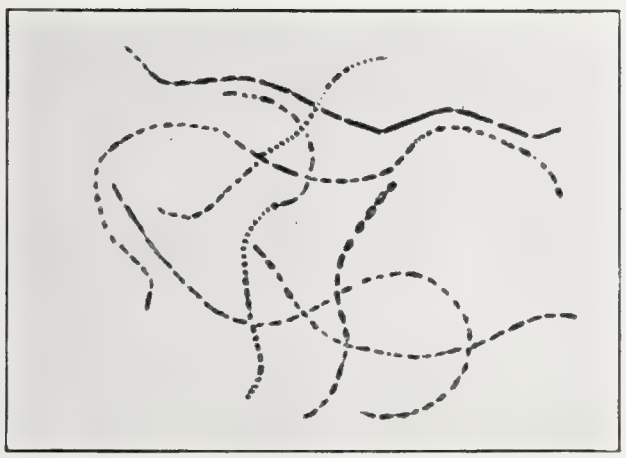
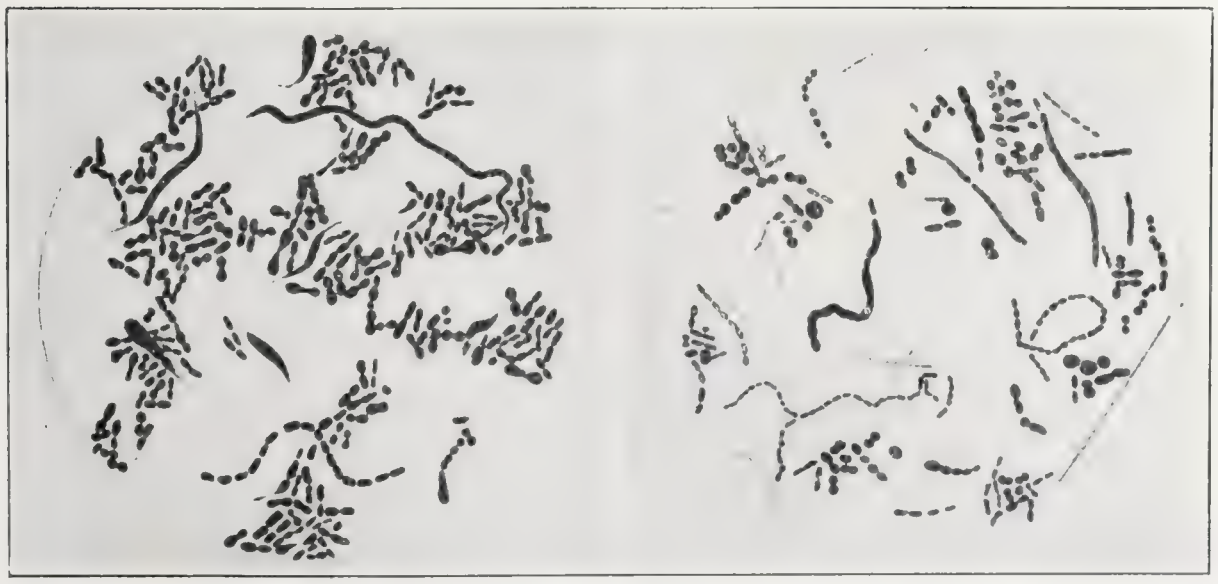


Fig. 12.

Fig. 14.



a *b*

Fig. 13.

PLATE E.

FIG. 15 (p. 58).—*Bact. aceti E. Chr. Hansen* (1879, original fig. 77, 1911). ×1,000.

16 (p. 59).—*B. radicicola. Conn* (1900, original fig. 26, p. 99). ×1,000.

17 (p. 62).—*Metallacter Bacillus Perty* (1852, original fig. XV, 26 *a*). ×1,000.

18 (p. 62).—Different cell forms of bacilli. *Nägeli* (1877, original fig. 2).

19 (p. 62).—"Glycerin-Aethylbacterie" (Fitz). *Buchner* (1882, original fig. 10). × 4,000.

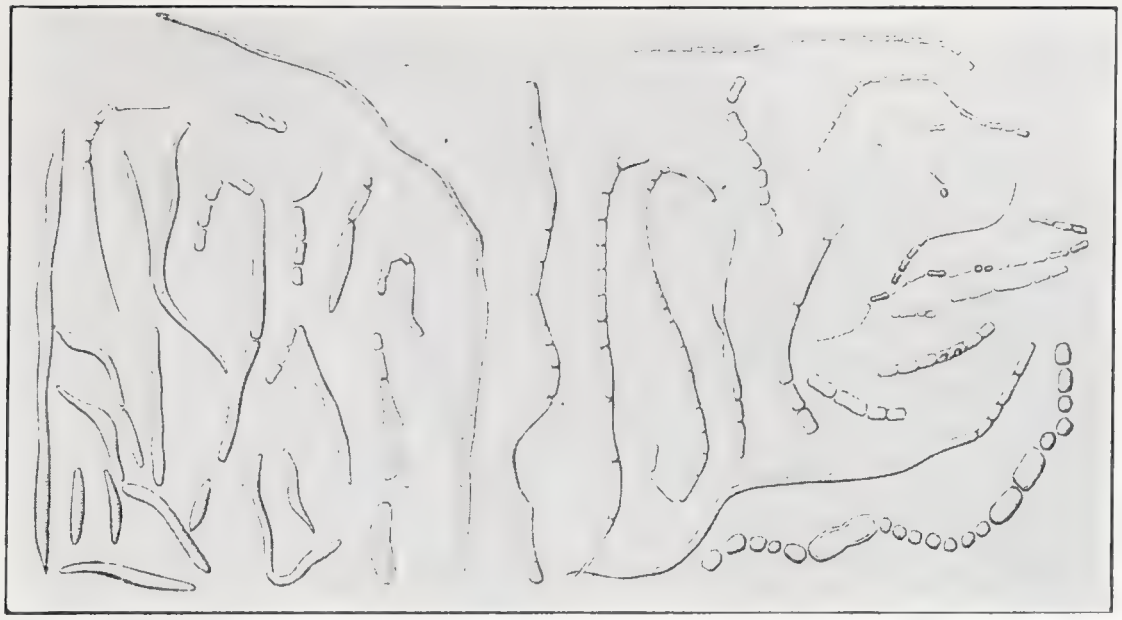


Fig. 15.

Fig. 16.

Fig. 17.

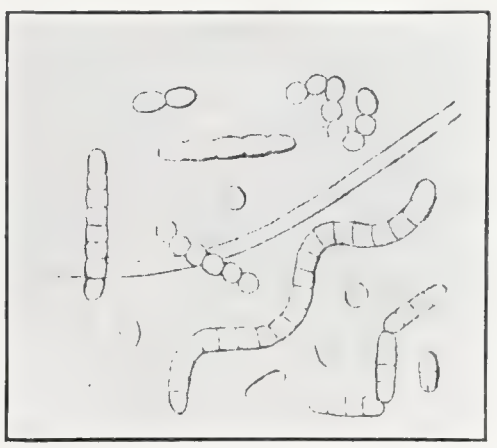


Fig. 18.

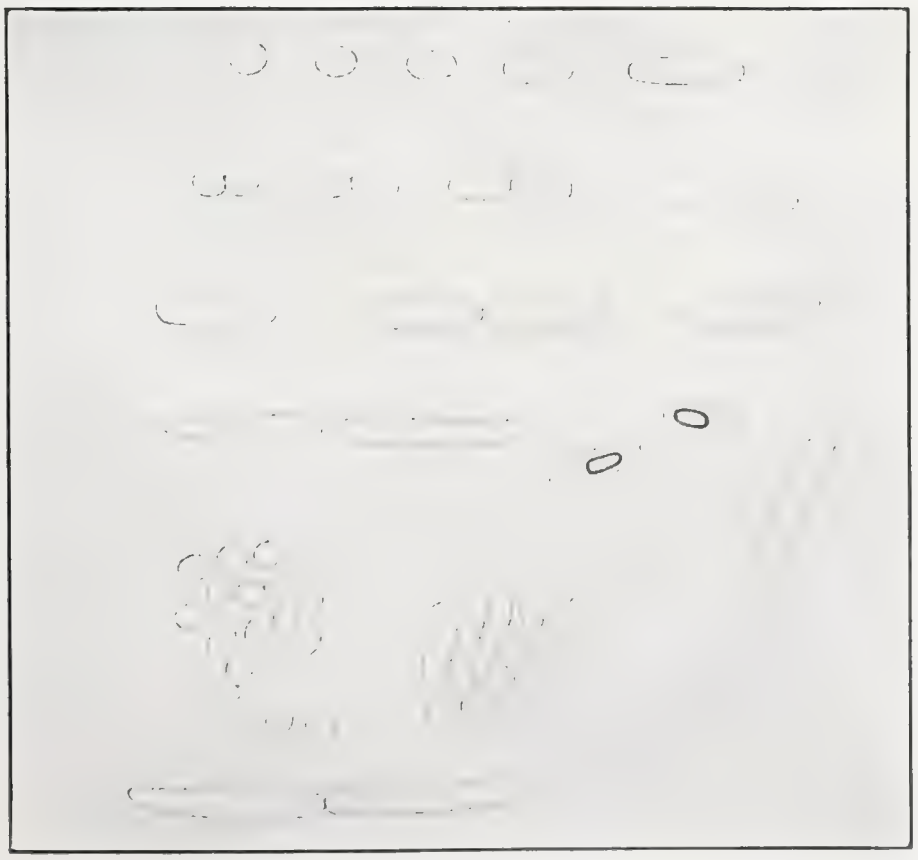


Fig. 19.

PLATE F.

FIG. 20 (p. 62).—*Bac. mycoides. Olsen* (1897, original fig. V, 14). ×900.

21 (p. 63).—*B. anthracis. E. Klein* (1883, original figs. XXI, 1–3) ×1,000.

22 (p. 63).—*B. anthracis. E. Klein* (1885, original fig. 77, p. 109). ×450.

23 (p. 63).—*B. anthracis. E. Klein* (1894, original figs. I, 1 and 2). ×1,000.

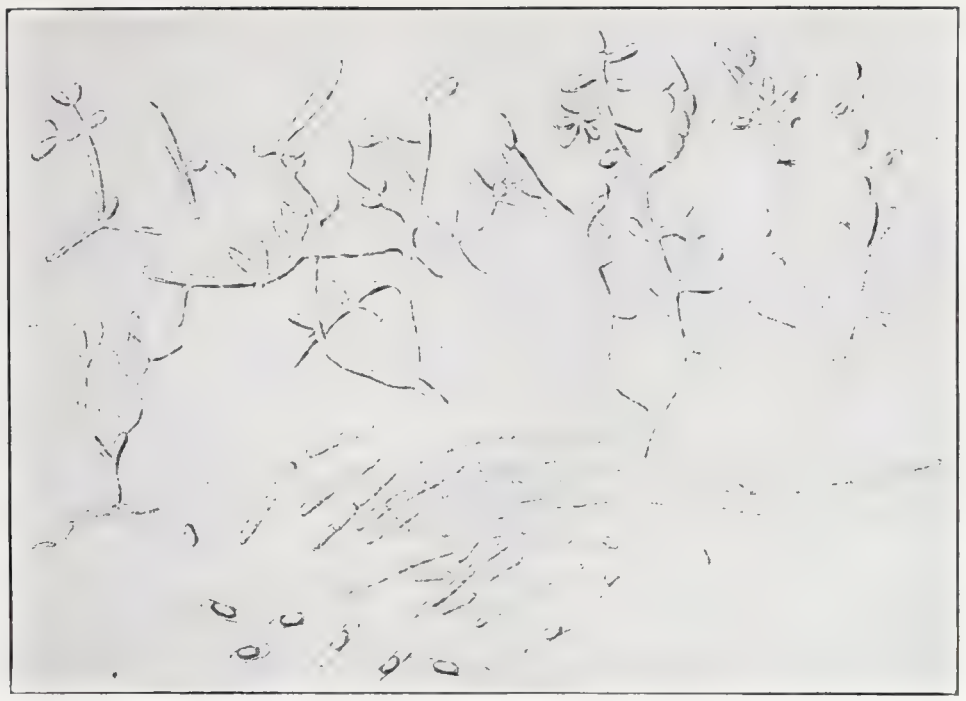


Fig. 20.

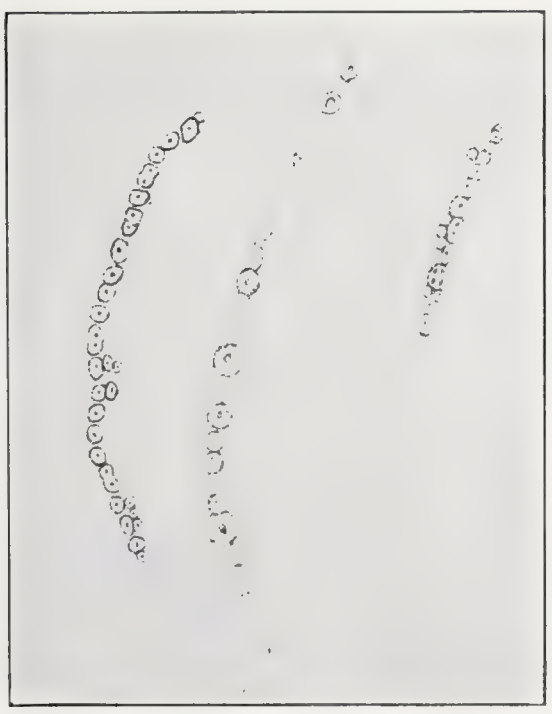


Fig. 21.

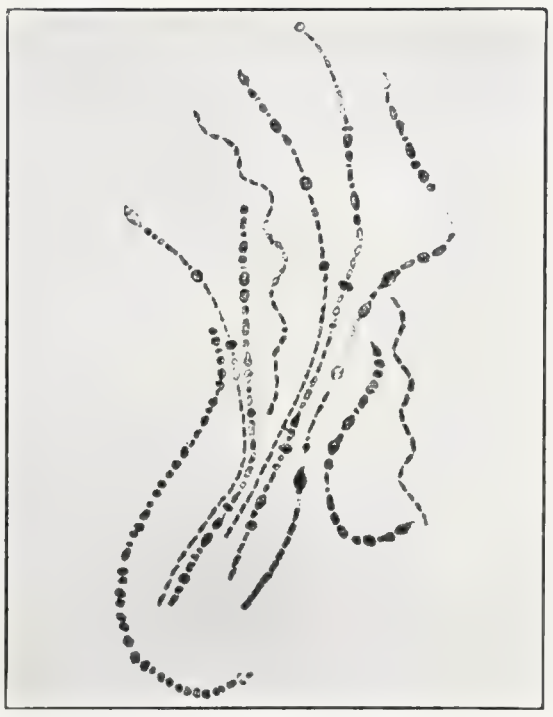


Fig. 22.

Fig. 23.

PLATE G.

FIG. 24 (p. 65).—*B. tumescens Zopf* (1883, original fig. 23, p. 66). ×900.

25 (p. 66).—*Clostridium butyricum* (above) and *Clostridium Polymyxa* (below), *Prażmowski* (1880, original figs. II, 1, 2, 6, 7). ×1,020.

26 (p. 66).—"Micro-oidia" of *B. amylobacter*. *Bredemann* (1909, original figs. II, 32–36). ×2,450.

Fig. 24.

Fig. 26.

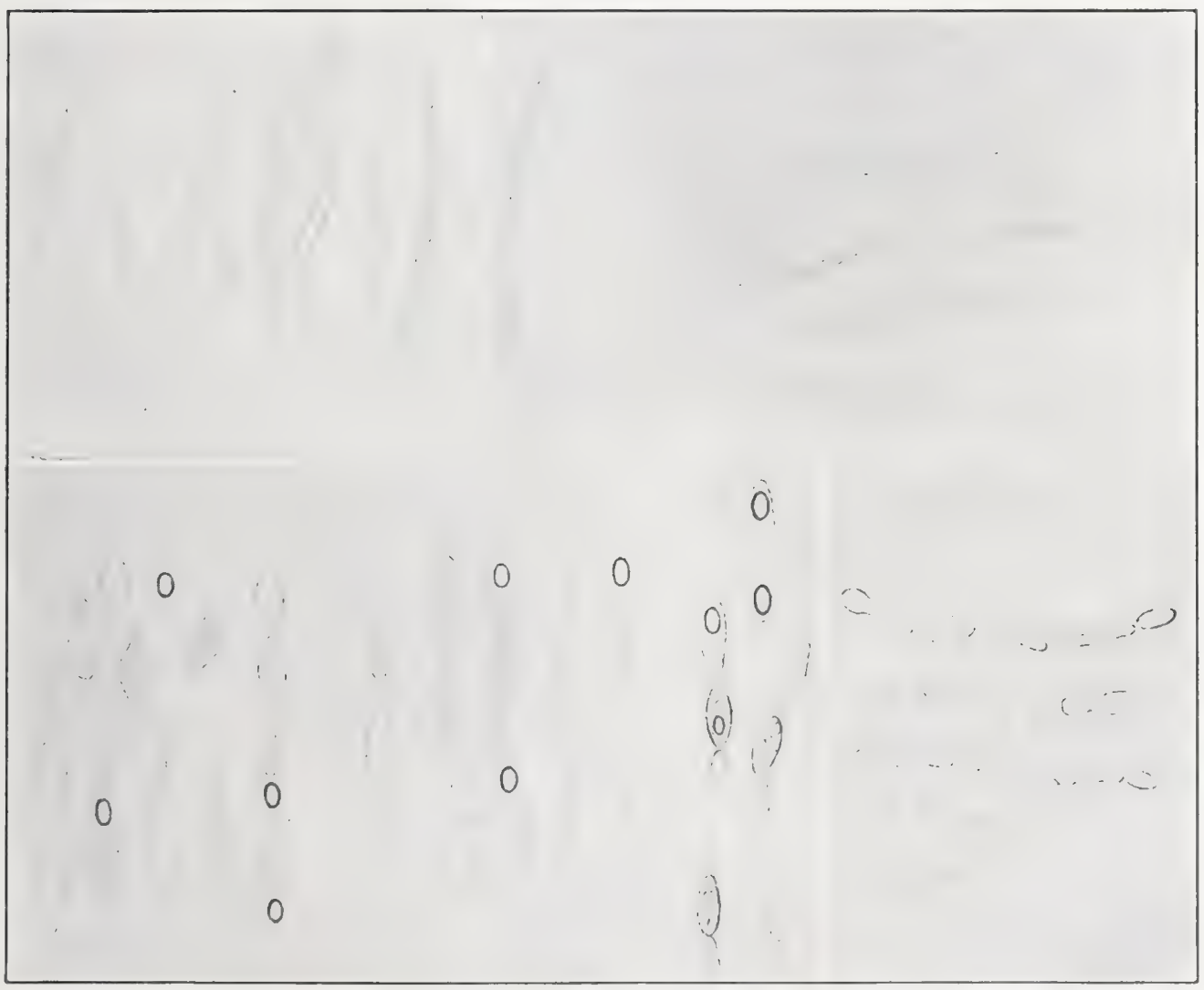


Fig. 25.

PLATE H.

FIG. 27 (p. 67).—*B. Chauvoei, Ghon* and *Sachs* (1903, original figs. 13, 14, 16–18). ×1,000.

28 (p. 68).—*Vibrio Rugula Prazmowski* (1880, original figs. I, 10, and 11). ×1,020.

29 (p. 72).—*Spirillum endoparagogicum Sorokin* (1887). ×1,375.

30 (p. 73).—*Spirillum rubrum. Meirowsky* (1914 *b*, original figs. V*b*, 6 and 7). ×2,000.

31 (p. 73).—*Spirochaeta icterohaemorrhagica Inada* et al. (1916, original figs. 69 and 70).

32 (p. 75).—*Bact. repens Miehe* (1913, original figs. II, 9, and 10). ×1,120–1,200.

33 (p. 77).—*B. mallei. Marx* (1899, original figs. 1–4).

Fig. 27.

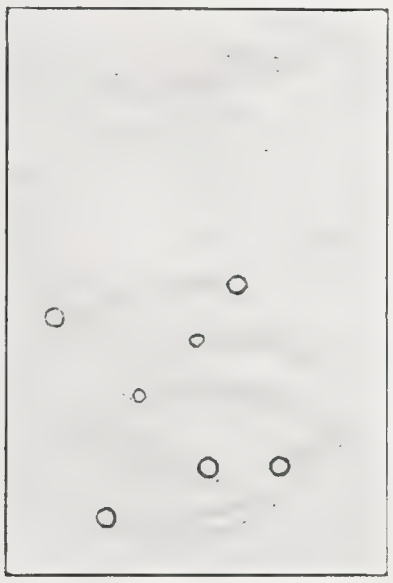


Fig. 28.

Fig. 29.

Fig. 30.

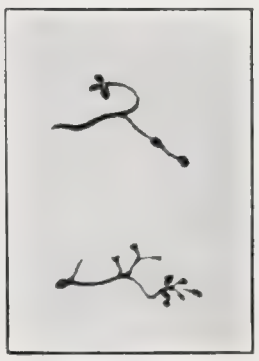


Fig. 31.

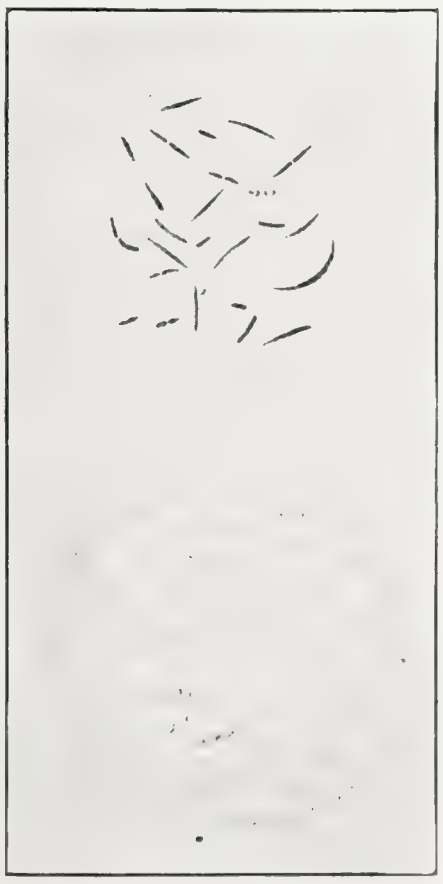


Fig. 32.

Fig. 33.

160266 21 18

PLATE J.

FIG. 34 (p. 80).—*Pseudo-diphtheria bacilli.* *Babes* (1895, original fig. 3). ×800.

35 (p. 81).—*B. enzymicus* *Mellon* (1917, original fig. 2, p. 88).

36 (p. 82).—*B. leprae.* *Lutz* (1886, original figs. 7–11, p. 81). ×1,000.

37 (p. 82).—*B. leprae.* *Kedrowski* (1910, original fig. 37). ×1,000.

38 (p. 84).—*B. tuberculosis.* *Metchnikoff* (1888 *a*, original fig. V, 20). ×1,200.

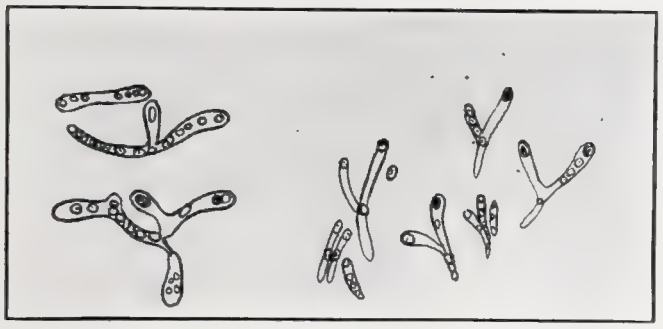


Fig. 34.

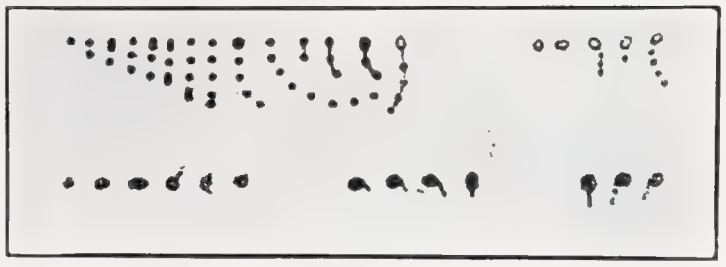


Fig. 36.

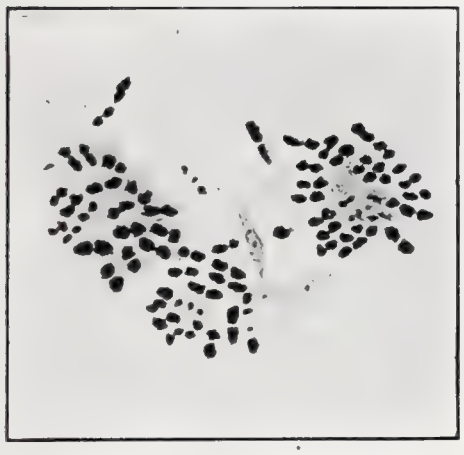


Fig. 35.

Fig. 37.

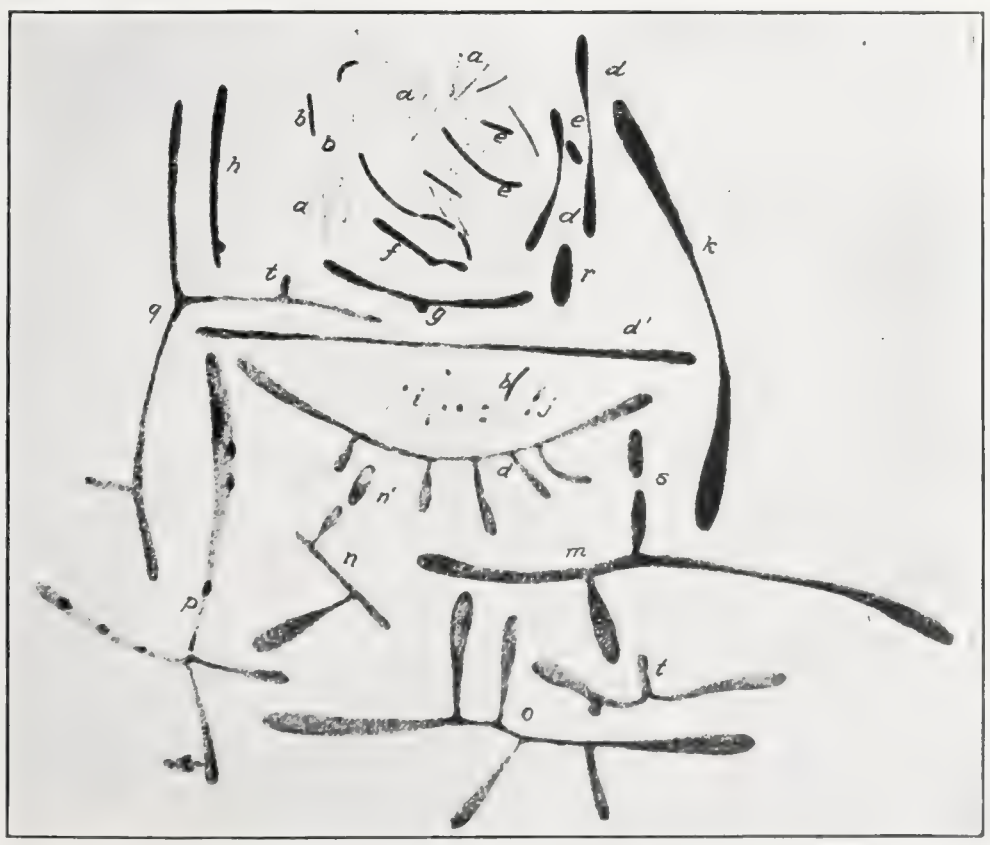


Fig. 38.

PLATE K.

FIG. 39 (p. 87).—Cladothrix (*a–f*) and Actinomyces (*g–i*). *Migula* (1900, original fig. 45, p. 39). *e* and *h* ×500; all others ×1,000.

40 (p. 91).—*Sporonema gracile Perty* (1852, original fig. 26 on Pl. XV). ×1,000.

41 (p. 92).—Germinating gonidia. *Kindfleisch* (original fig. XVIII, 1).

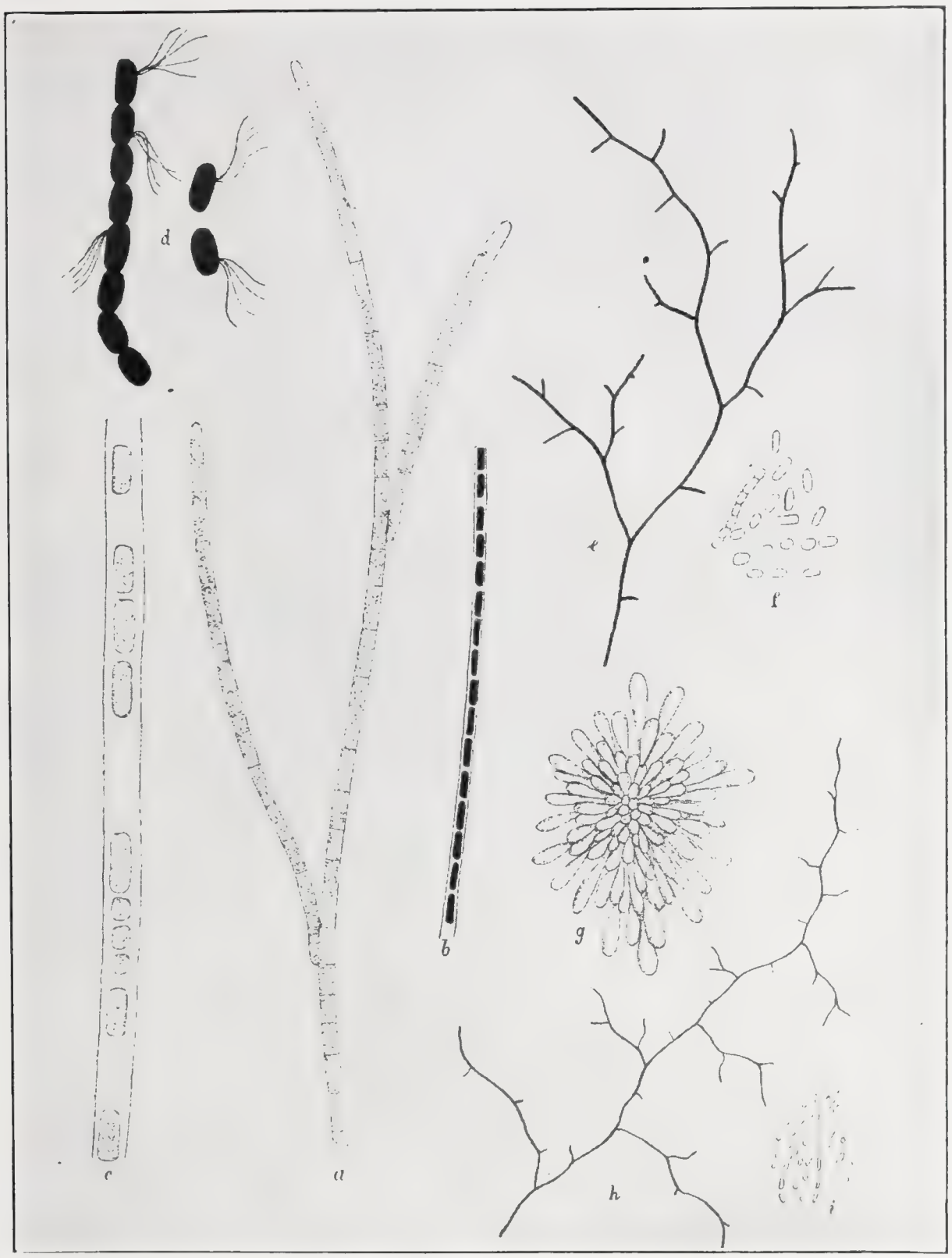


Fig. 39.

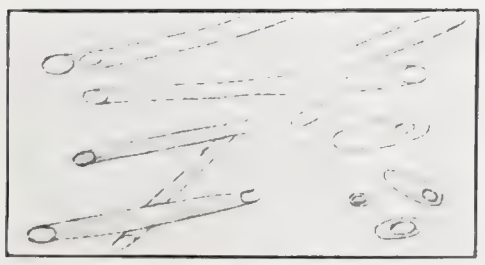


Fig. 40.

Fig. 41.

PLATE L.

FIG. 42 (p. 91).—Gonidia and Spirilla. *Perty* (1852, original figs. 28, 29B, and 31 on Pl. XV). ×1,000.

43 (p. 92).—"Sporangium" and "spore" of Crenothrix. *F. Cohn* (1870, original figs. 11 and 13). ×500–800.

44 (p. 93).—Formation of gonidia and gonidangia. *Billroth* (1874, original fig. 36). ×1,185.

45 (p. 93).—Formation and liberation of gonidia. *Billroth* (1874, original fig. 42). ×1,185.

46 (p. 94).—*Phragmidiothrix multiseptata*. *Engler* (1882, original fig. 24). ×400.

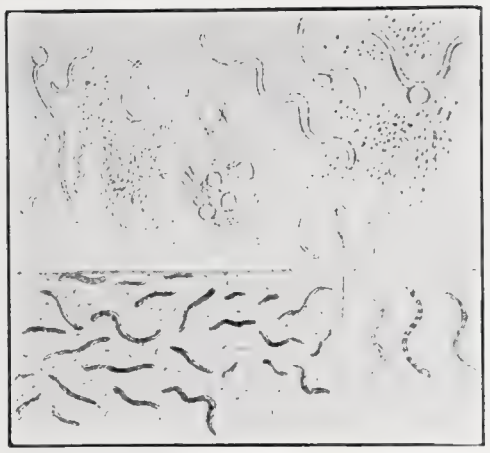


Fig. 42.

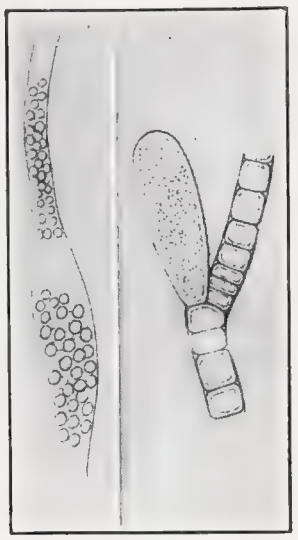


Fig. 43.

Fig. 44.

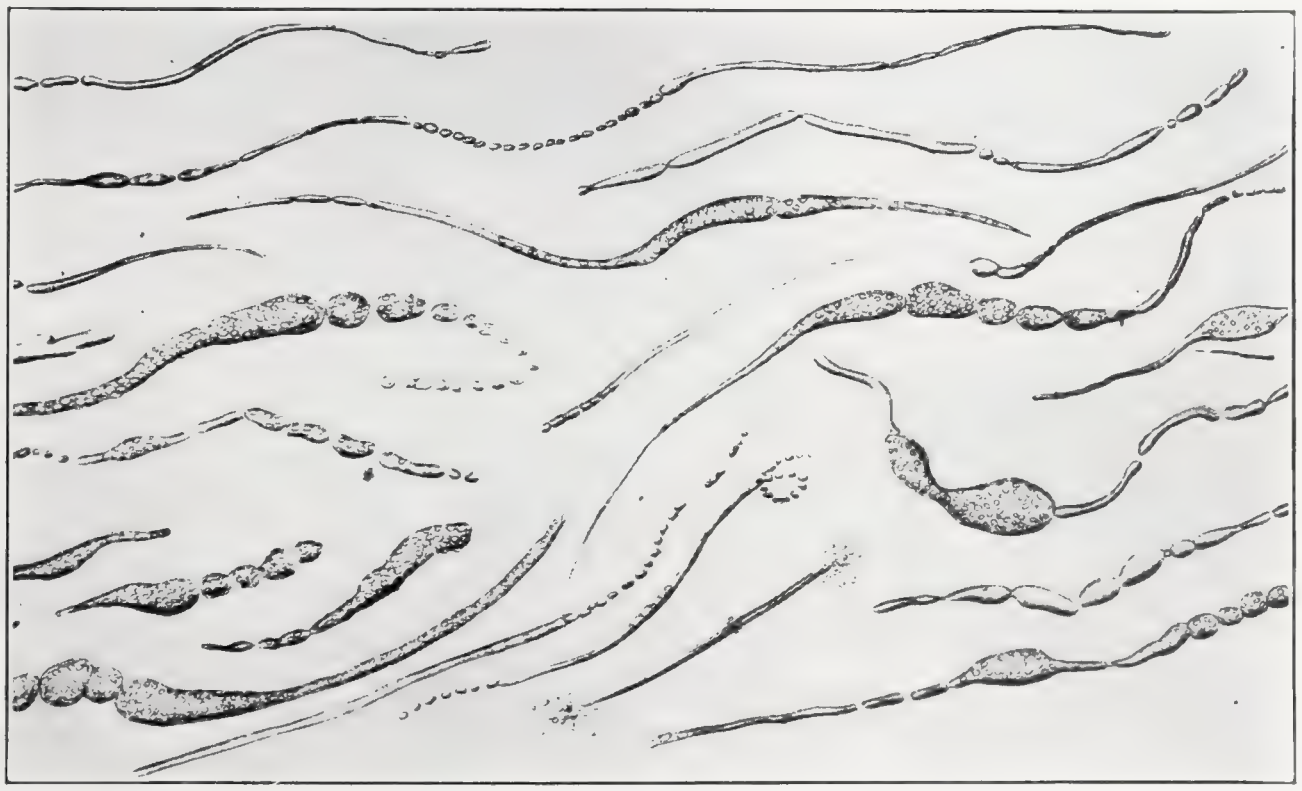


Fig. 45.

Fig. 46.

PLATE M.

FIG. 47 (p. 94).—*Crenothrix Kühniana*. *Zopf* (1883, original fig. 6). ×600.

48 (p. 94).—*Beggiatoa alba*. *Zopf* (1883, original fig. 27). ×900.

49 (p. 96).—*Vibrio cholerae*. *Hueppe* (1885, original fig. 2, p. 622).

50 (p. 96).—*Metabacterium polyspora Chatton* et *Pérard* (1913, p. 1233). ×2,000.

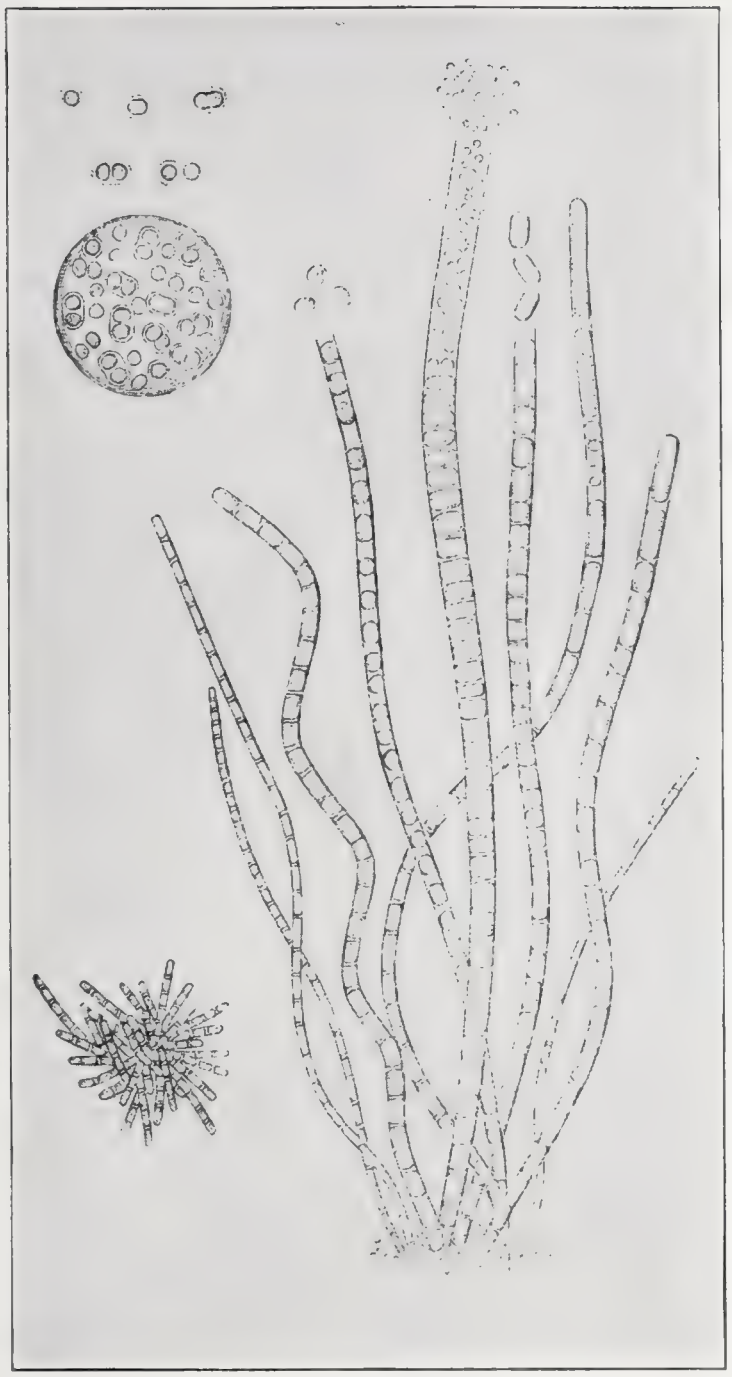


Fig. 47.

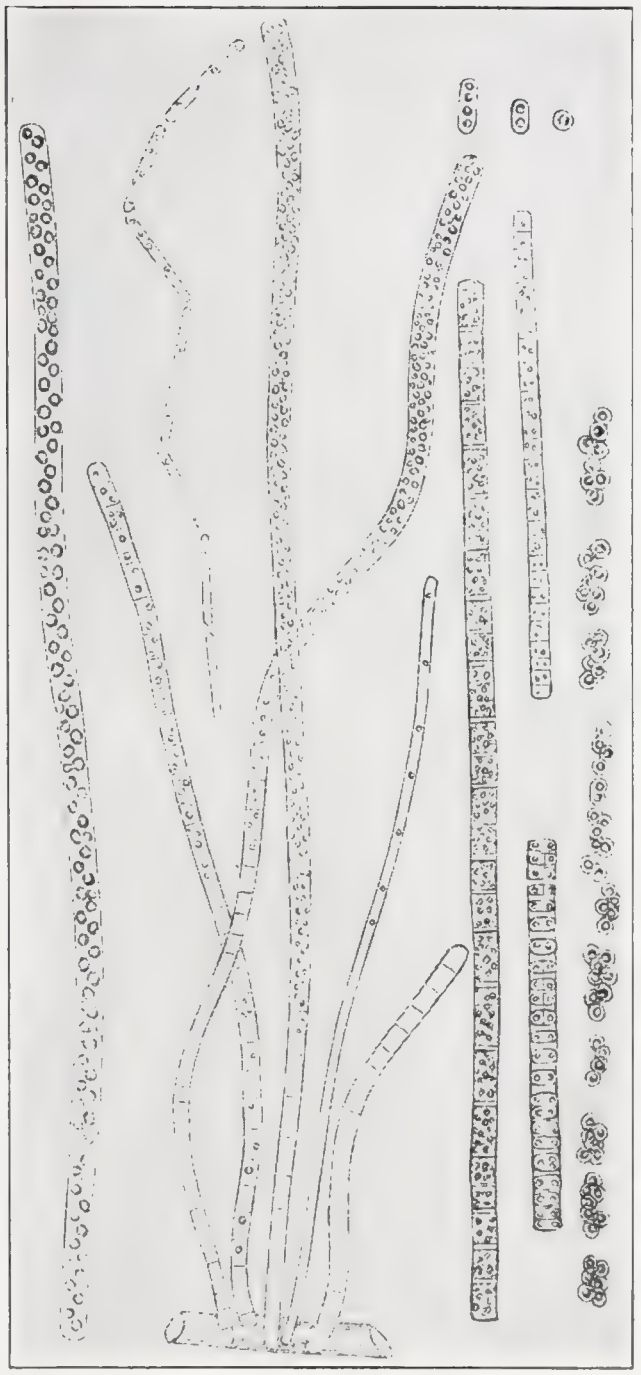


Fig. 48.

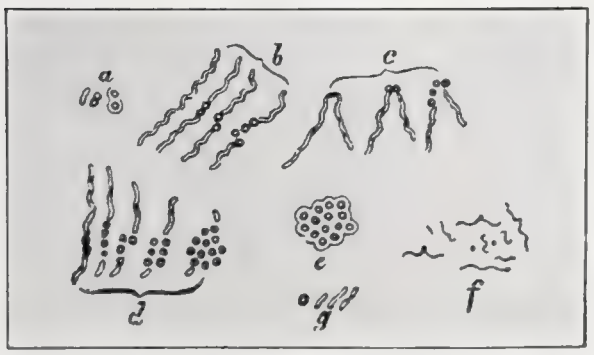


Fig. 49.

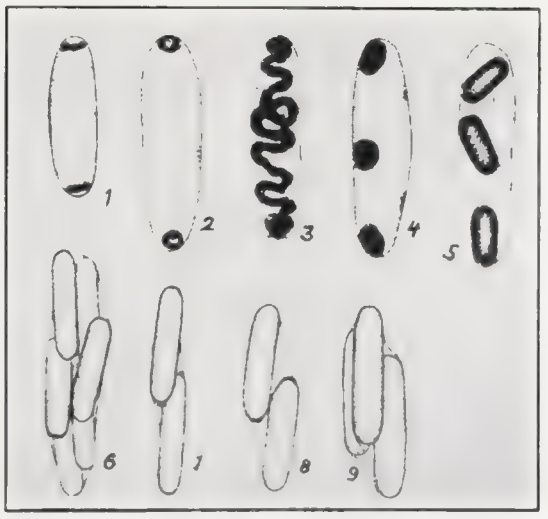


Fig. 50.

PLATE N.

FIG. 51 (p. 97).—*B. muralis.* *Tomaschek* (1888, p. 183). ×1,000.

52 (p. 98).—*Jodococcus vaginatus.* *W. Miller* (1889, original fig. 15, p. 54). ×1,100.

53 (p. 100).—*Ascobacterium luteum.* *Babes* (1895, original fig. 13 B). ×800.

54 (p. 101).—*B. typhi* and *V. cholerae* with "conidia." *Almquist* (1908, original figs. 5, 13, and 21).

55 (p. 102).—*B. tuberculosis.* *Crookshank* (1896, original fig. XI, 12). ×1,200.

56 (p. 102).—*Eubacillus multisporus Dangeard* (1891, original fig. VIII, 4). ×1,000.

57 (p. 103).—*Bact. oxydans.* *Henneberg* (1898, original fig. 1). ×1,000 (?).

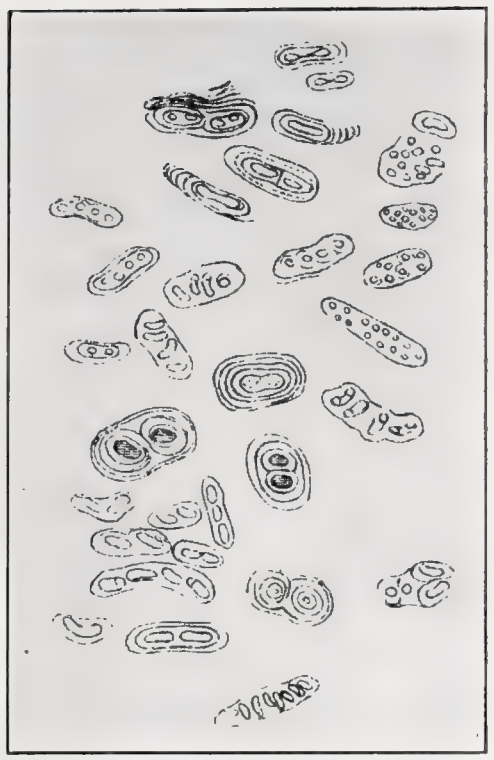


Fig. 51.

Fig. 53.

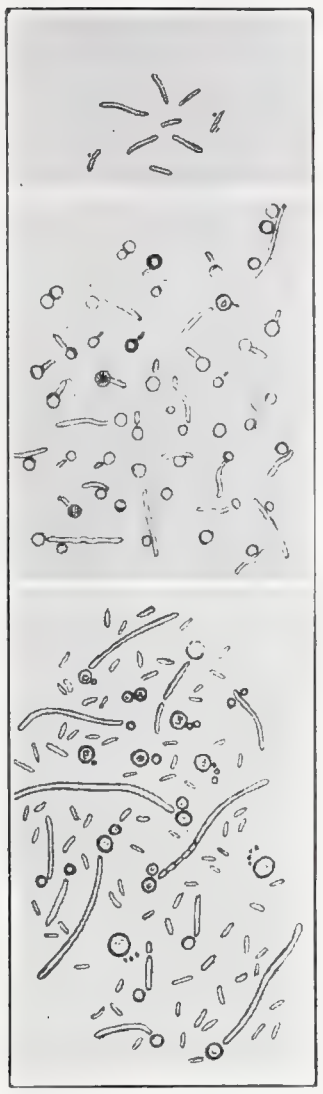
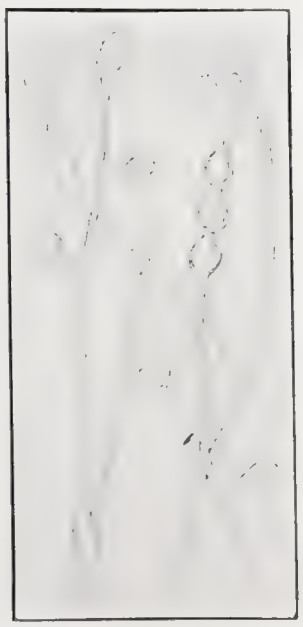


Fig. 54.

Fig. 52.

Fig. 55.



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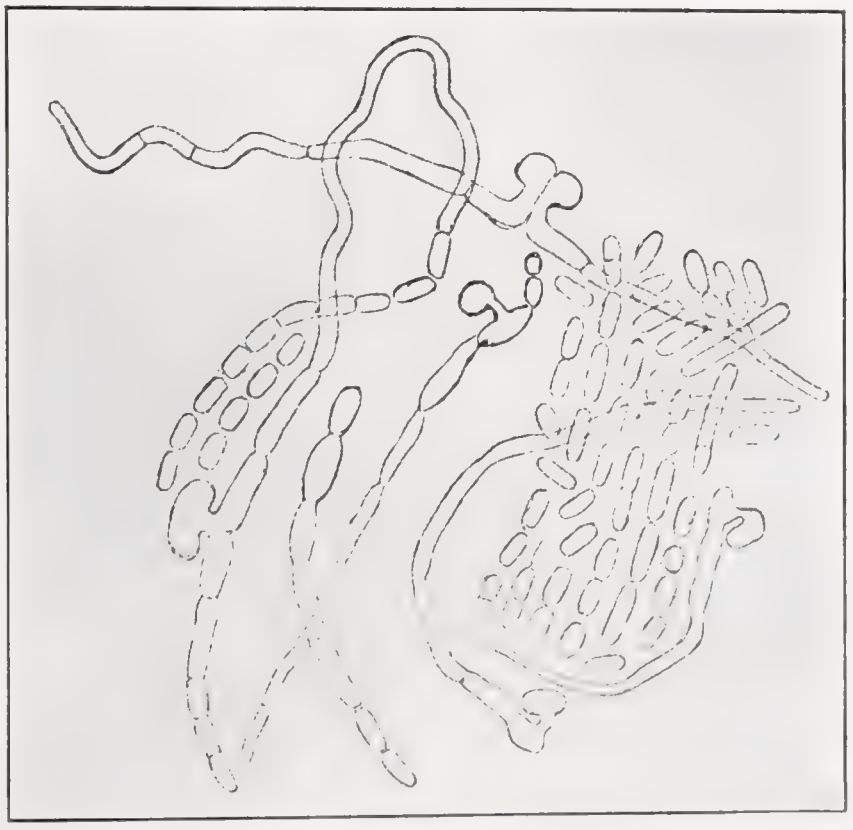


Fig. 57.

PLATE O.

FIG. 58 (p. 103).—Upgrowth of *B. pestis*. *N. K. Schultz* (1901 *a*, original fig. I). ×1,000.

59 (p. 106).—"Spore" formation by spirochaets. *Fantham* (1911, original fig. 5, p. 489).

60 (p. 106).—*Spirochaeta anodontae*. *Bosanquet* (1911, original figs. 21 and 22). ×2,000.

61 (p. 111).—Regeneration of *B. pestis*. *N. K. Schultz* (1901 *a*, original fig. II). ×1,000.

62 (p. 117).—"Plasmoptysis" of *V. cholerae*. *A. Fischer* (1903, original fig. 27). ×1,500.

63 (p 123).—*Saprospira grandis* (left) and *Cristispira tapetos* (right). *Gross* (1912, original figs. 8 and 9).

64 (p. 123).—Microcysts of *B. cohaerens* (×1,000) and of *B. ruminatus* (×3,500). *A. Meyer* (1901 *b*, original figs. XX, 4 and 15).

65 (p. 123).—*Myxococcus macrosporus*. *Zukal* (1897, original fig. 3). ×1,400.

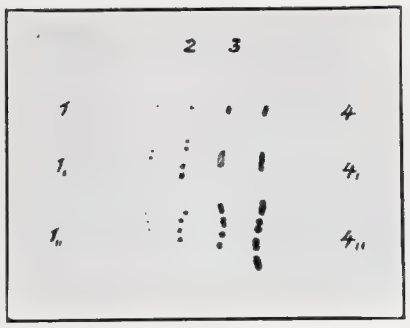


Fig. 58.

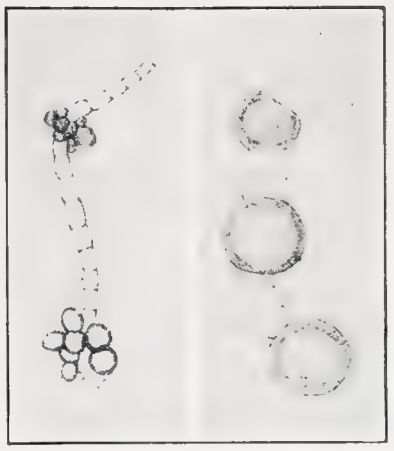


Fig. 64.

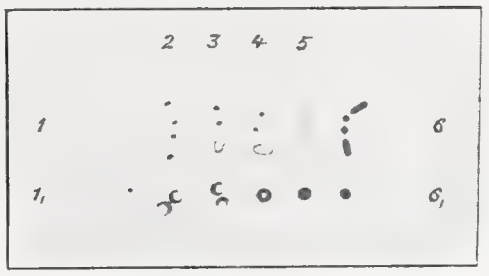


Fig. 61.

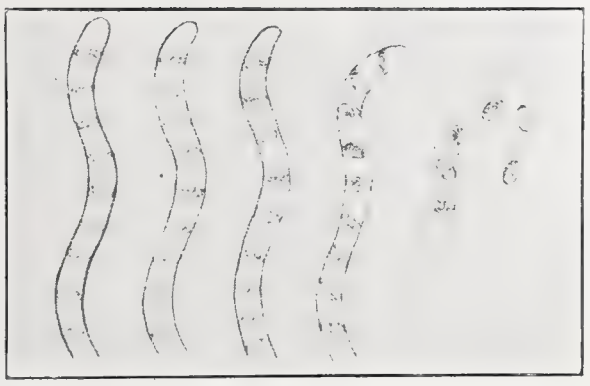


Fig. 59.

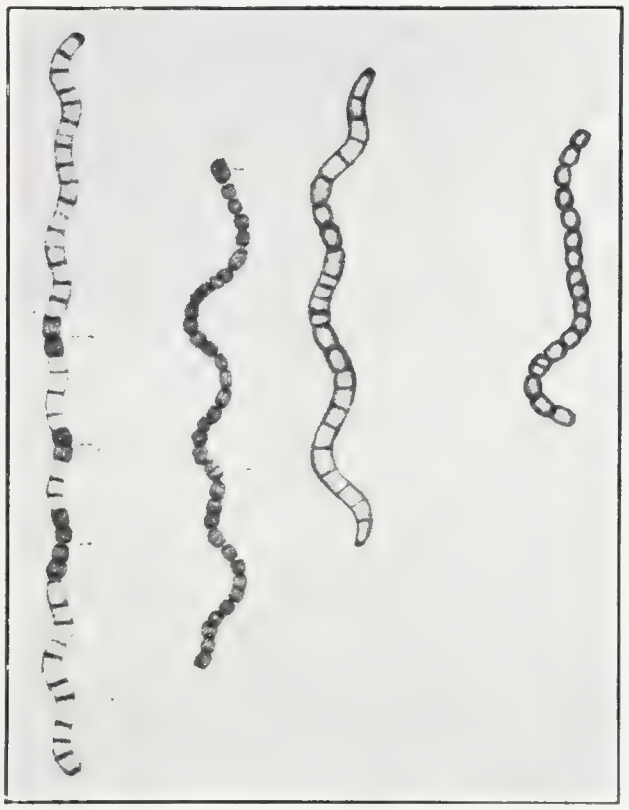


Fig. 63.

Fig. 60.

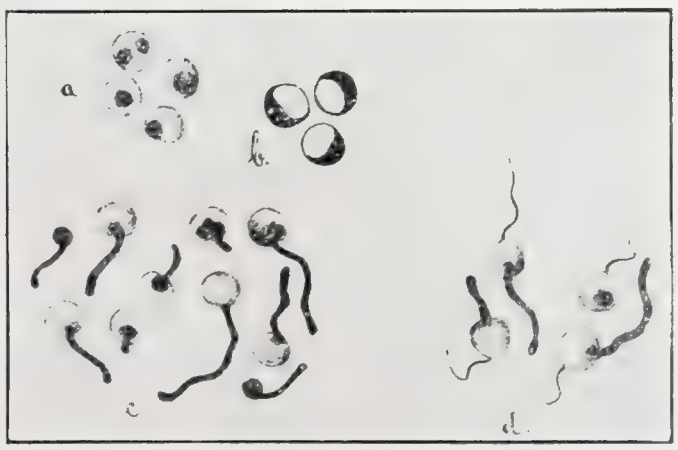


Fig. 62.

Fig. 65.

PLATE P.

FIG. 66 (p. 124).—Gonidia formation of *B. radicicola*. *Morck* (1891, original figs. III, 4, and V, 12).

67 (p. 125).—Gonidangia of *B. radicicola*. *Morck* (1891, original figs. III, 2 *b-d*).

68 (p. 125).—Gonidangia from diphtheria. *Letzerich* (1876, original figs. XII, 1–4). ×480.

69 (p. 128).—Crenothrix branching. *Migula* (1900, original fig. 43 *f* and *g*). ×1,000.

70 (p. 130).—Upgrowth of *Cladothrix dichotoma*. *Billet* (1890, original figs. IV, 4 and 5). ×1,600.

71 (p. 132).—*Spirochaeta icterohaemorrhagica* with regenerative bodies. *Inada, Ido, Hoki, Kaneko,* and *Ito* (1916, original figs. 40–47 on Pl. 61).

72 (p. 132).—*Streptococcus pyogenes*. *Hewlett* (1902, original fig. II*a*). ×1,500.

73 (p. 136).—*Spirobacillus Cienkowskii*. *Metchnikoff* (1889, original fig. 14, Pl. 1). ×2,020.

74 (p. 143).—Coiled spirochaets. *Prowazek* (1907*a*, original fig. I, 8*b*).

75 (p. 143).—Encysted spirochaets. *Inada* et al. (1916, original figs. 71 and 72).

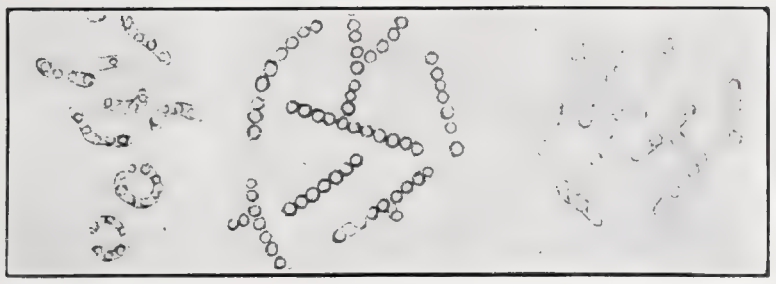


Fig. 66.

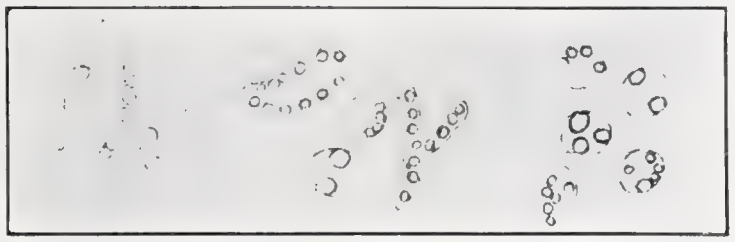


Fig. 67.

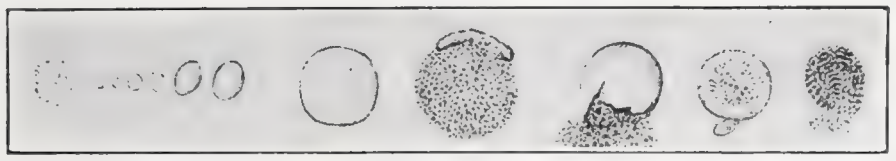


Fig. 68.

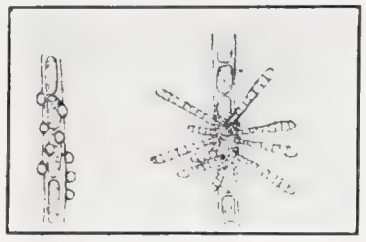


Fig. 69.

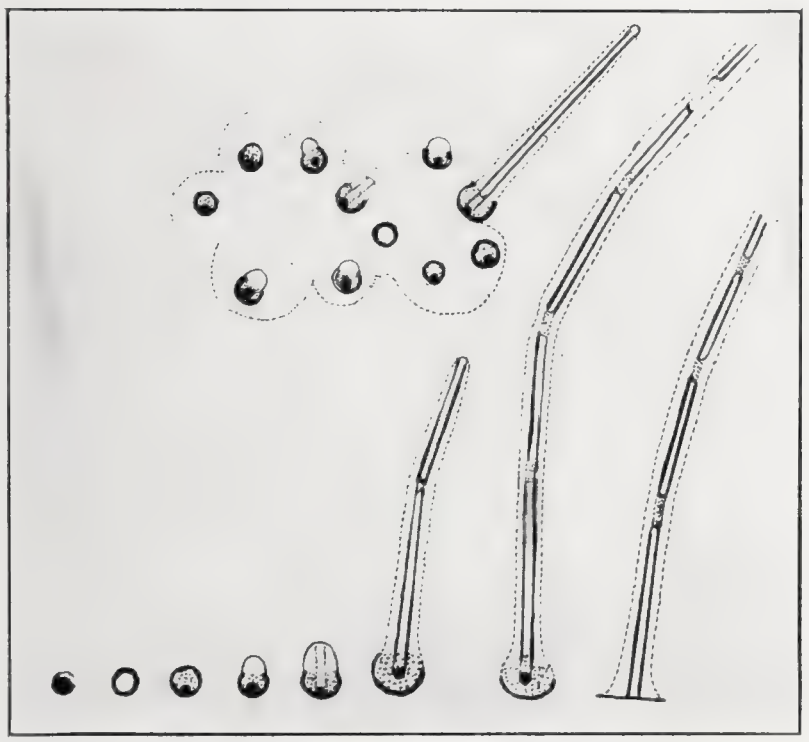


Fig. 70.

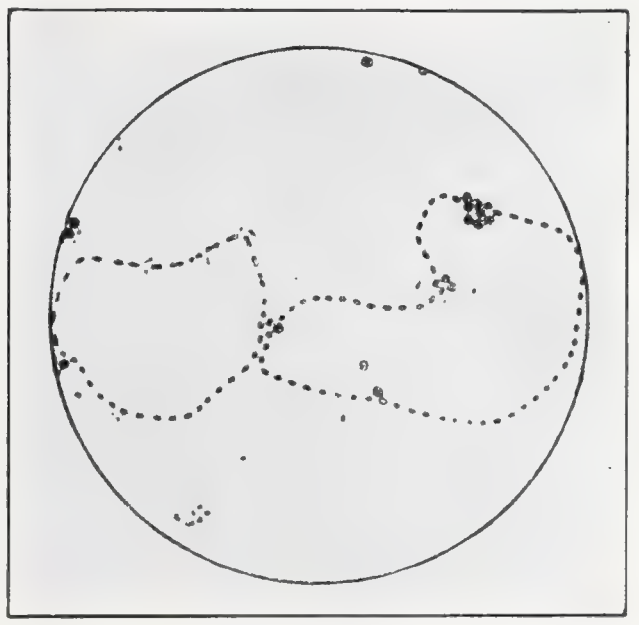


Fig. 72.

Fig. 71.

Fig. 73.

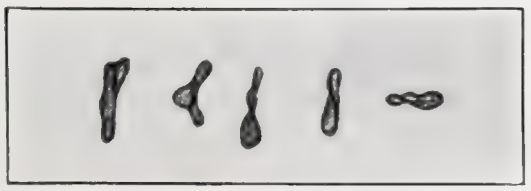


Fig. 74.

Fig. 75.

PLATE Q.

FIG. 76 (p. 148).—Bacterial development from "micro-gonidia." *Karsten* (1869, original fig. V).

77 (p. 148).—Rods and "microzymas." *Béchamp* (1883, original fig. I, 4). ×650.

78 (p. 167).—Development of protozoa and fungi. *Pineau* (1845 *a*, Pl. 4 bis). ×400. Figs. 8–10, *Monas lens;* 11–13, *Enchelys ovata;* 14–20, *Vorticella infusionum;* 21–27, *Penicillium glaucum.*

79 (p. 168).—Development of protozoa (*Podophyra* and *Actinophrys*). *Perty* (1852, original figs. VIII, 9 and 10). ×1,000.

Fig. 76.

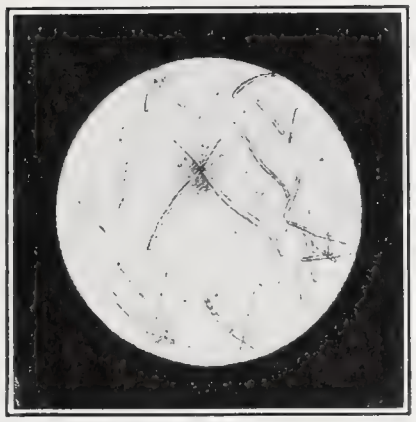


Fig. 77.

Fig. 79.

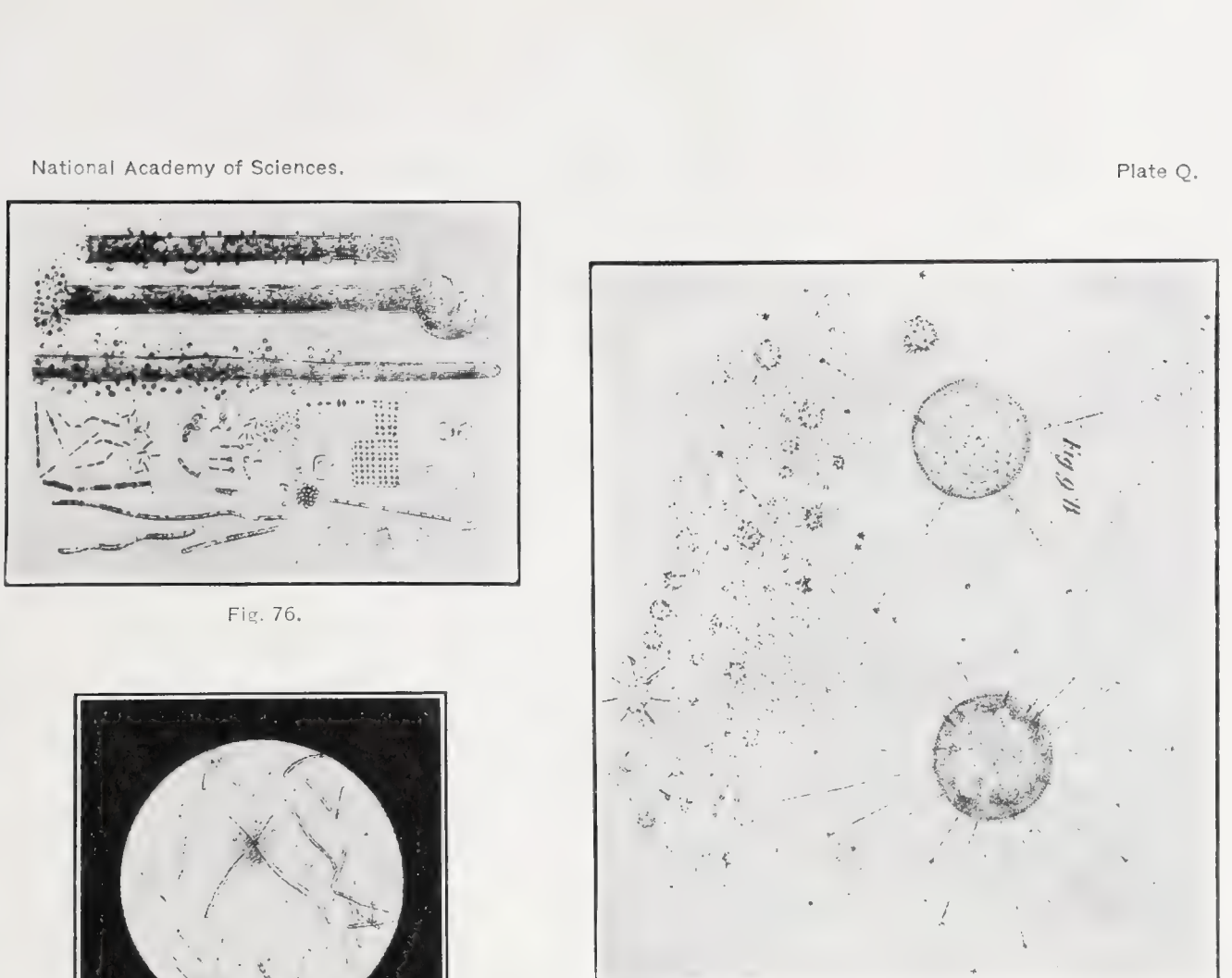


Fig. 78.

PLATE R.

FIG. 80 (p. 170).—Growth obtained from diphtheria. *Letzerich* (1876, original figs. XII, 5–10). ×480.

81 (p. 172).—Regeneration of yeast cells in vinegar. *Béchamp* (1883, original fig. I, 5). ×650.

82 (p. 173).—Symplasm from leprous tissue. *Lutz* (1886, original figs. 1–6). ×1,000.

83 (p. 174).—Growth of bacteria from root nodules. *Frank* (1890, original figs. VIII, 34 *a–c*). *a* and *b* ×660, *c* ×1,030.

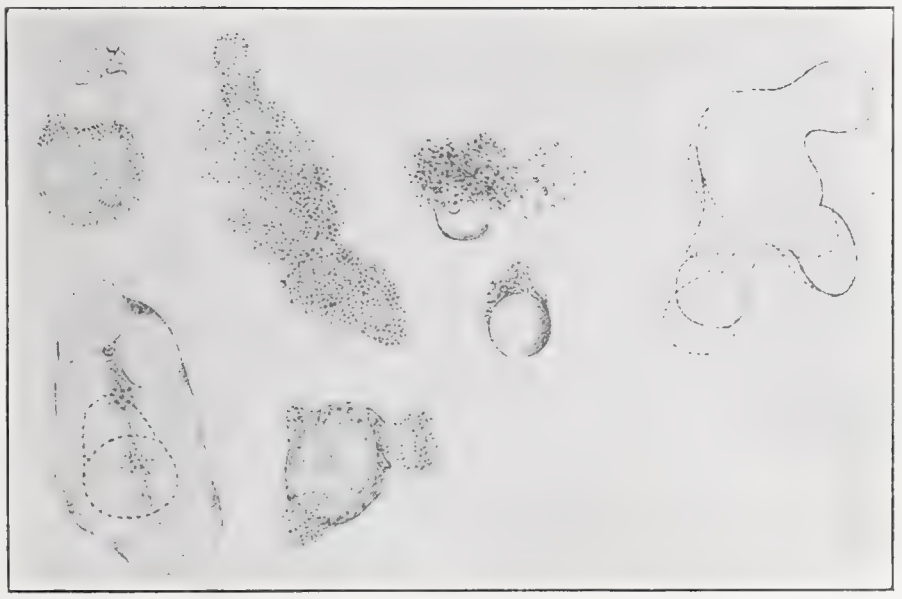


Fig. 80.

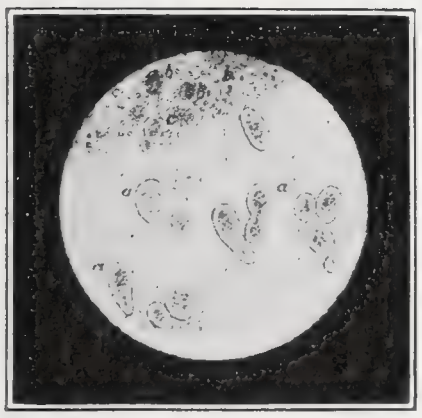


Fig. 81.

Fig. 82.

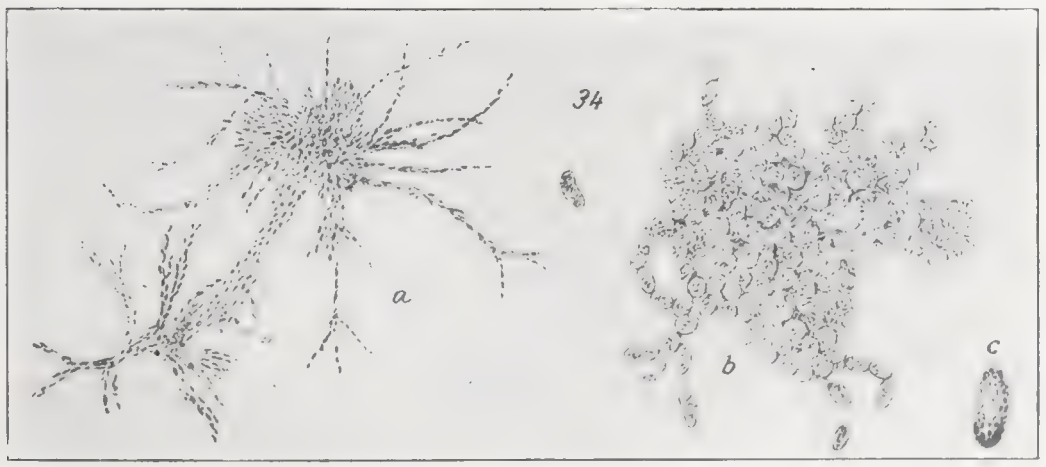


Fig. 83.

PLATE S.

FIG. 84 (p. 174).—Symplasm from root nodules. *Morck* (1891, originals figs. 3 and 12 *c* and *f*).

85 (p. 175).—Irregular cells of *B. cyanogenes*. *Neelsen* (1880, original fig. XI, 10). ×650.

86 (p. 177).—*Spirillum rubrum*. *Meirowsky* (1914 *b*, original figs. V *b*, 4–5). ×2,000.

87 (p. 180).—*Myxococcus ruber*. *Baur* (1905, original fig. 3, p. 113).

88 (p. 181).—Cyst of Polyangium. *Zukal* (1897, original fig. 8). ×50.

89 (p. 201).—*Spirochaeta gallinarum*. *Prowazek* (1906 *b*, original figs. II, 10 *c*, 11 *a* and *b*). ×1,560.

Fig. 84.

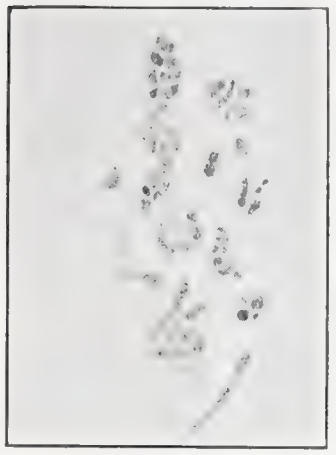


Fig. 85.

Fig. 86.

Fig. 87.

Fig. 88.

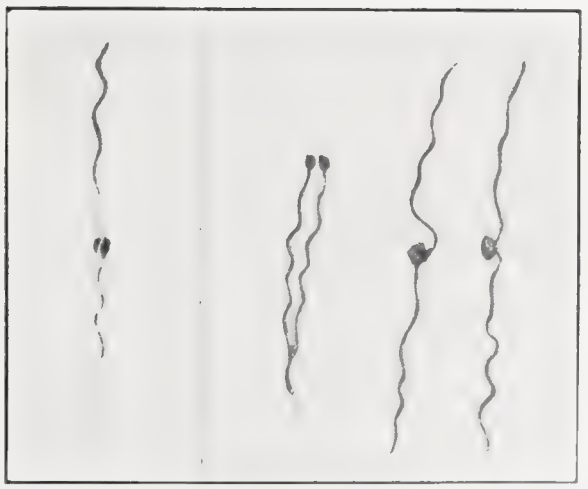
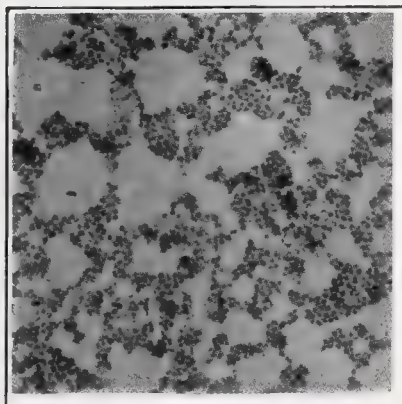


Fig. 89.

PLATE I.

FIG. 1. (p. 43): Microc. candicans. *Löhnis* and *Smith* (1916 *a*, original fig. 13). ×1,000.
2. (pp. 43, 135): Microc. candicans. *Löhnis* and *Smith* (1916 *a*, original fig. 37). ×1,000.
3. (pp. 43, 135): Microc. candicans. *Löhnis* and *Smith* (1916 *b*, original fig. 14). ×1,000.
4. (pp. 43, 135): Microc. candicans. *Löhnis* and *Smith* (1916 *b*, original fig. 15). ×1,000.
5. (pp. 43, 135): Microc. rubefaciens. *Matzuschita* (1900, original fig. 2). ×1,000.
6. (pp. 43, 135): Microc. flavus. *Matzuschita* (1900, original fig. 4). ×1,000.
7. (p. 44): Microc. melitensis. *Jordan* (1916, original fig. 99). ×1,000.
8. (pp. 44, 190: Microc. candicans. *Löhnis* and *Smith* (1916 *b*, original fig. 40). ×1,000.
9. (pp. 48, 191): Poliomyelitis. *Rosenow* and *Towne* (1917, original fig. X, 7*c*). ×1,000.
10. (p. 48): Poliomyelitis. *Mathers* (1917, original figs. I, 1 and 3). ×1,200.
11. (pp. 48, 142): Streptoc. lactis. *Löhnis* and *Smith* (1916 *b*, original fig. 10). ×1,000.
12. (p. 48): Streptoc. tyrogenus. *Migula* (1900, v. II, original fig. I, 2). ×1,000.



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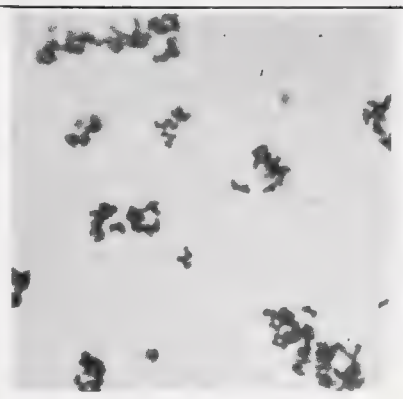

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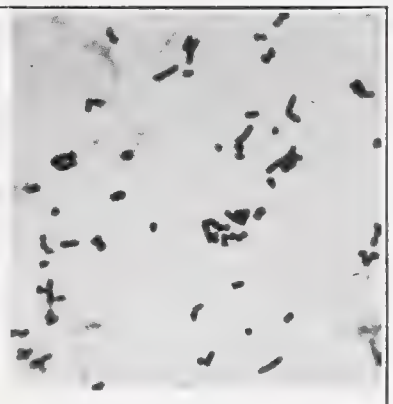

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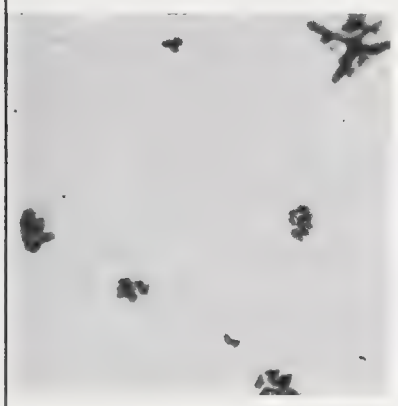

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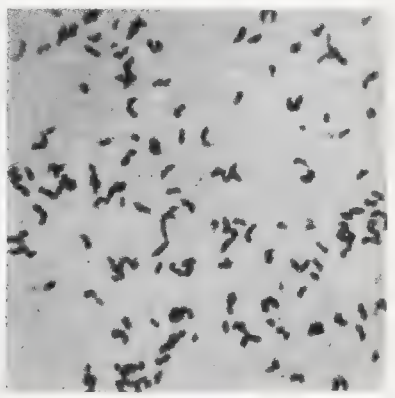

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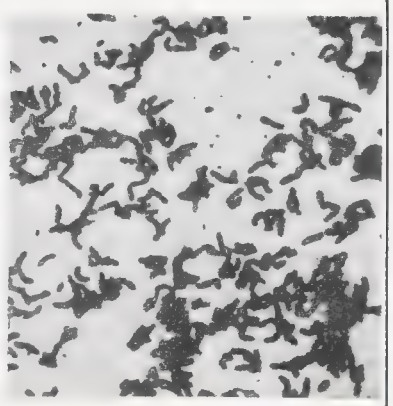

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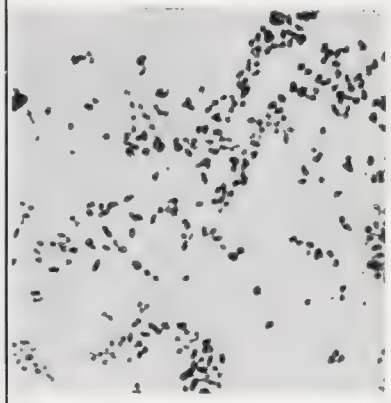

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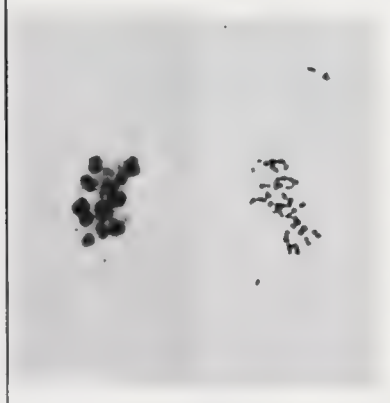

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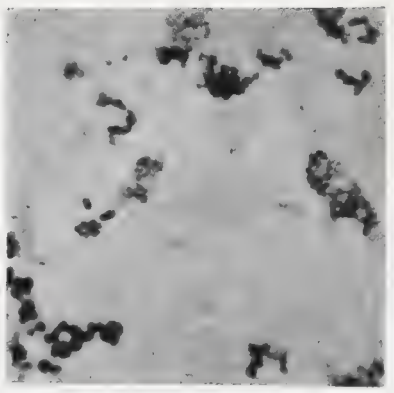

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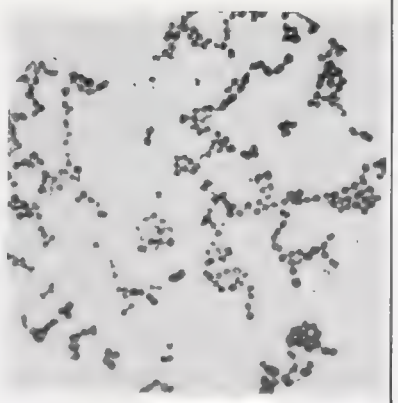

12

PLATE II.

FIG. 13. (p. 48): Streptoc. equi. *Migula* (1900, v. II, original fig. II, 5). ×1,000.
14. (p. 48): Sarcina flava. *Löhnis* and *Smith* (1916 *b*, original fig. 11). ×1,000.
15. (pp. 48, 142): Sarc. flava. *Löhnis* and *Smith* (1916 *b*, original fig. 12). ×1,000.
16. (pp. 48, 190): Sarc. flava. *Löhnis* and *Smith* (1916 *b*, original fig. 54). ×1,000.
17. (pp. 48, 190): Sarc. flava. *Löhnis* and *Smith* (1916 *b*, original fig. 55). ×1,000.
18. (pp. 49, 134): Bact. bruneum. *Matzuschita* (1900, original fig. 6). ×1,000.
19. (p. 49): Azotob. vitreum. *Löhnis* and *Hanzawa* (1914, original fig. 24). ×800.
20. (p. 49): Azotob. vitreum. *Löhnis* and *Hanzawa* (1914, original fig. 22). ×800.
21. (p. 49): Azotob. vitreum. *Löhnis* and *Hanzawa* (1914, original fig. 23). ×800.
22. (pp. 52, 192): Typhus exanthematicus. *P. Th. Müller* (1913, original fig. 2). ×1,000.
23. (p. 52): Typhus exanthematicus. *P. Th. Müller* (1913, original fig. 5). ×1,000.
24. (pp. 52, 193): Typhus exanthematicus. *P. Th. Müller* (1913, original fig. 1). ×1,000.

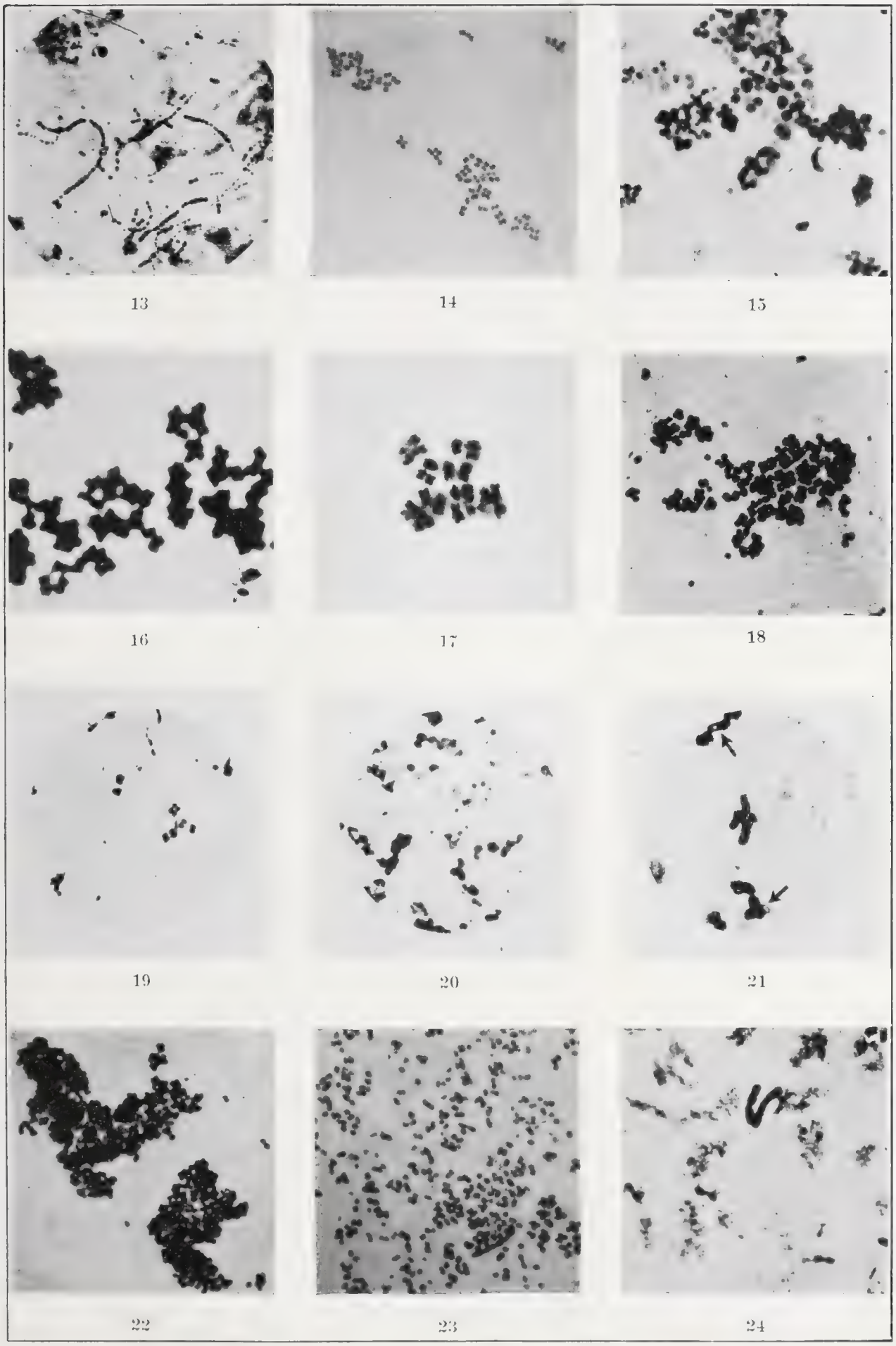

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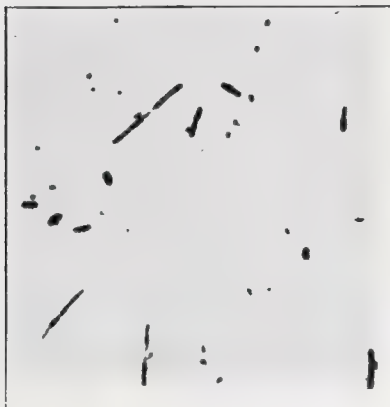
PLATE III.

FIG. 25. (p. 53): B. erysipelatos suum. *Itzerott* und *Niemann* (1895, original fig. 40). ×1,000.
26. (p. 52): B. erysipeloides. *Rosenbach* (1909, original fig. XIII, 5). ×1,000
27. (p. 52): B. erysipeloides. *Rosenbach* (1909, original fig. XII, 5). ×1,000.
28. (p. 53): B. murisepticum. *Rosenbach* (1909, original fig. XIII, 3). ×1,000.
29. (pp. 53, 192): B. erysipeloides. *Rosenbach* (1909, original fig. XII, 3). ×1,000.
30. (pp. 53, 134): B. cholerae gallinarum. *Itzerott* und *Niemann* (1895, original fig. 36). ×1,000.
31. (pp. 54, 101): B. pestis. *Muir* and *Ritchie* (1903, original fig. 148). ×1,000.
32. (p. 54): B. pestis. *Muir* and *Ritchie* (1903, original fig. 150). ×1,000.
33. (p. 54): B. pestis. *Muir* and *Ritchie* (1903, original fig. 147). ×1,000.
34. (pp. 54, 192): B. pestis. *Rowland* (1914, original fig. XIX, 12). ×1,000.
35. (pp. 54, 134): B. pestis. *Rowland* (1914, original fig. XXI, 17). ×1,000.
36. (pp. 56, 127): B. coli. *Matzuschita* (1900, original fig. 14). ×1,000.



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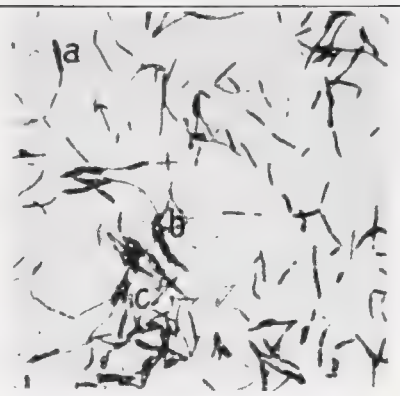

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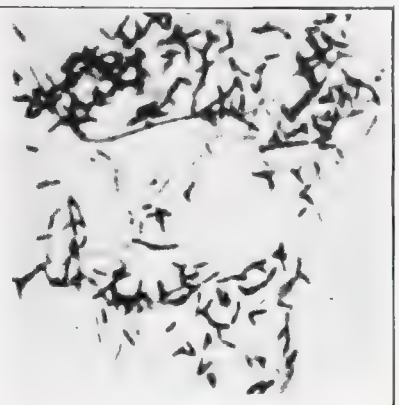

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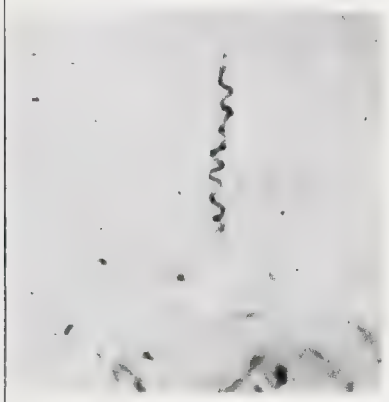

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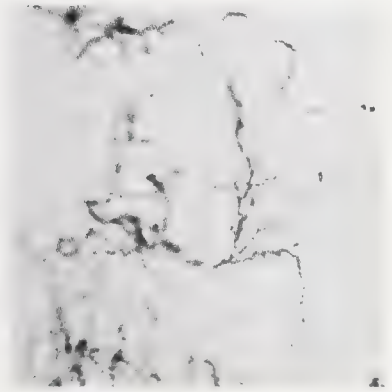

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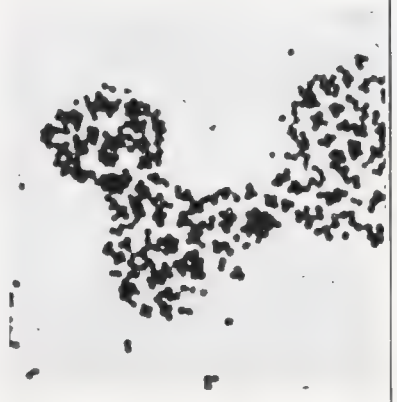

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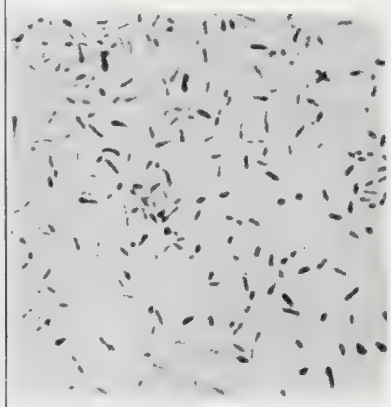

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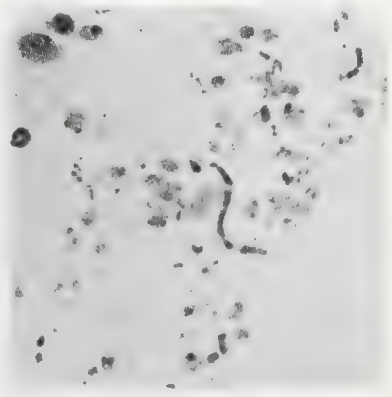

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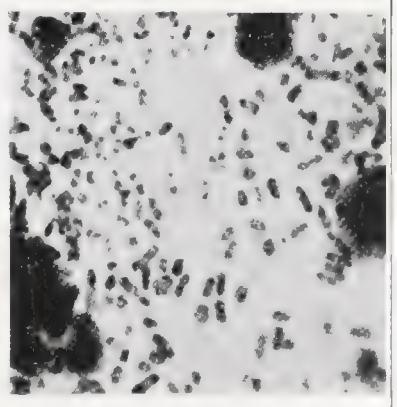

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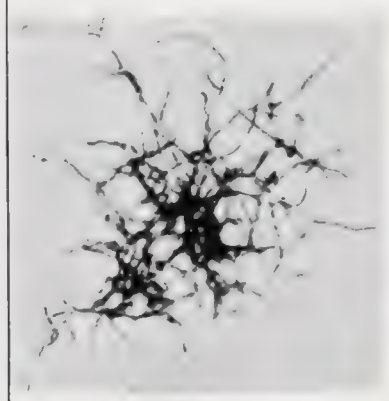

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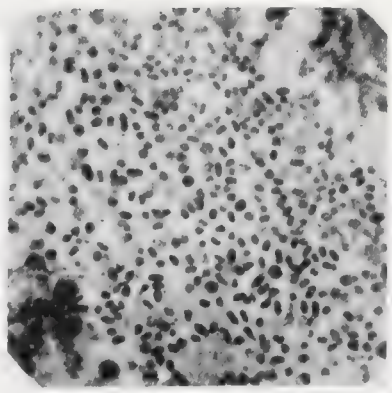

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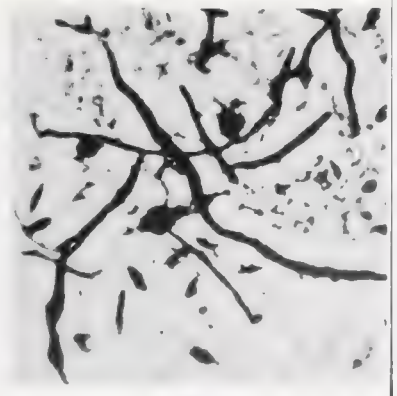

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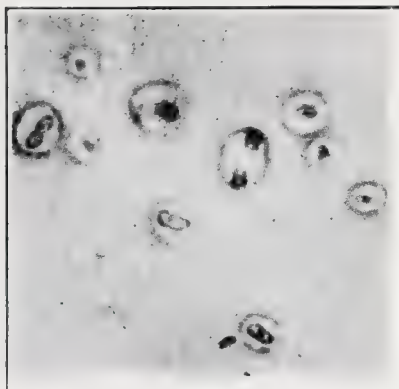
PLATE IV.

FIG. 37. (pp. 55, 185): B. pneumoniae. *Toenniessen* (1913, original fig. III). ×1,000.
38. (pp. 55, 185): B. pneumoniae. *Toenniessen* (1913, original fig. IV). ×1,000.
39. (pp. 55, 185): B. pneumoniae. *Toenniessen* (1913, original fig. V). ×1,000.
40. (pp. 55, 185): B. pneumoniae. *Toenniessen* (1913, original fig. VI). ×1,000.
41. (pp. 55, 185): B. pneumoniae. *Toenniessen* (1913, original fig. VII). ×1,000.
42. (pp. 55, 185): B. pneumoniae. *Toenniessen* (1913, original fig. VIII). ×1,000.
43. (p. 57): B. coli. *Kellerman* and *Scales* (1916, original fig. 8). ×1,000.
44. (pp. 57, 177): B. coli. *Kellerman* and *Scales* (1916, original fig. 11/12). ×1,000.
45. (pp. 57, 177): B. coli. *Kellerman* and *Scales* (1916, original fig. 9). ×1,000.
46. (p. 57): B. typhi. *Matzuschita* (1900, original fig. 16). ×1,000.
47. (p. 57): B. typhi. *Itzerott* und *Niemann* (1895, original fig. 18). ×1,000.
48. (p. 60): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 7). ×1,000.



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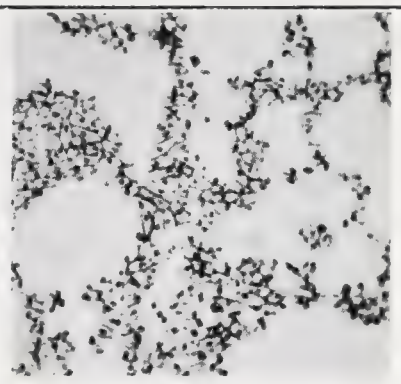

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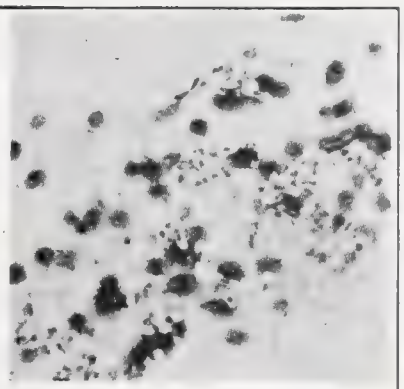

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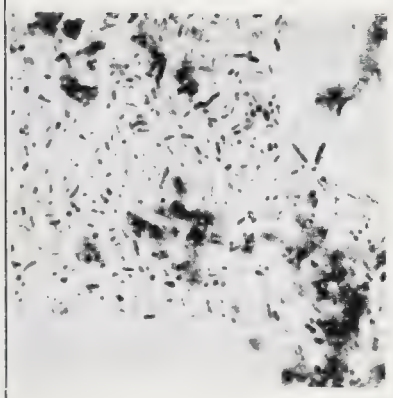

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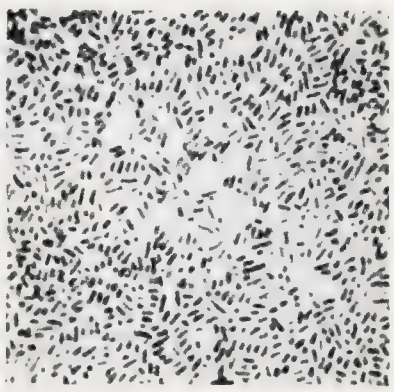

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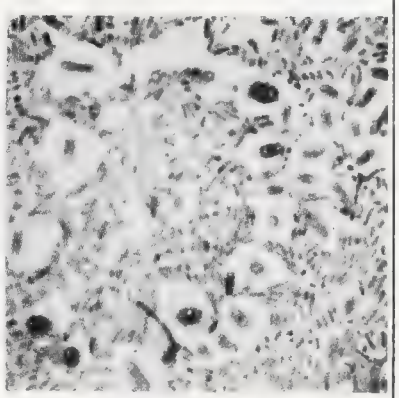

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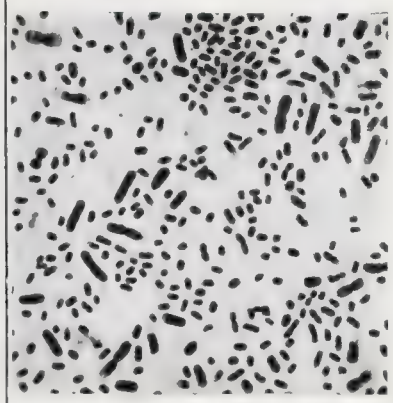

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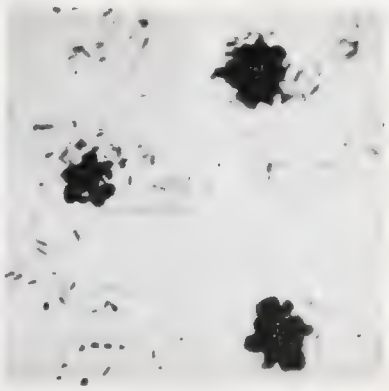

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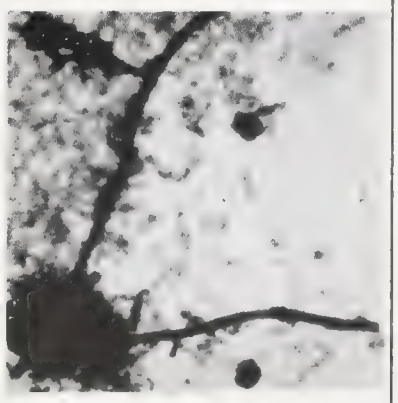

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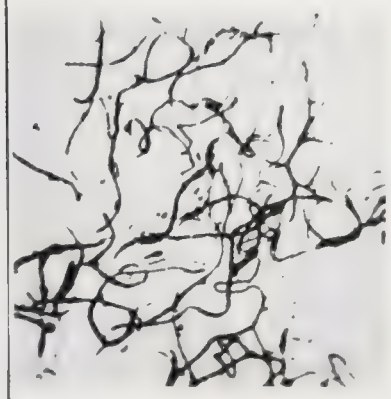

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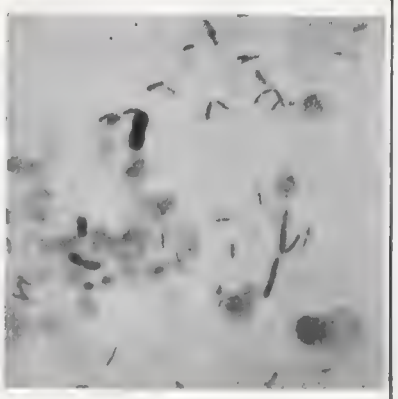

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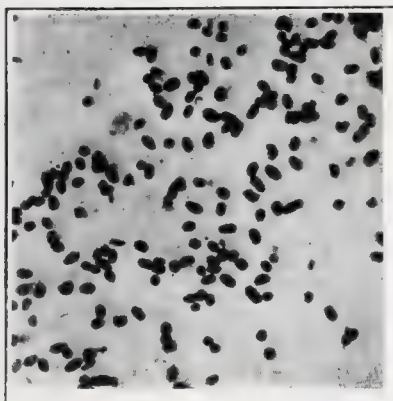
PLATE V.

FIG. 49. (p. 61): Nitrosomonas Zürich. *Winogradsky* (1892, original fig. 1). ×1,000.
50. (p. 61): Nitrosomonas Kasan. *Winogradsky* (1892, original fig. 4). ×1,000.
51. (p. 61): Nitrosomonas Java. *Winogradsky* (1892, original fig. 12). ×1,000.
52. (p. 61): Nitrobacter. *Winogradsky* (1891, original fig. XVIII, 1). ×1,000.
53. (p. 61): Nitrobacter. *Winogradsky* (1892, original fig. 16). ×1,000.
54. (p. 63): B. anthracis. *Itzerott* und *Niemann* (1895, original fig. 13). ×1,000.
55. (p. 63): B. anthracis. *Itzerott* und *Niemann* (1895, original fig. 14). ×1,000.
56. (p. 63): B. anthracis. *Itzerott* und *Niemann* (1895, original fig. 15). ×1,000.
57. (pp. 63, 138): B. anthracis. *Matzuschita* (1900, original fig. 31). ×1,000.
58. (p. 63): B. anthracis. *Henri* (1914, original fig. 4). ×925.
59. (pp. 63, 134): B. anthracis. *Henri* (1914, original fig. 5). ×925.
60. (p. 63): B. anthracis. *Henri* (1914, original fig. 6). ×925



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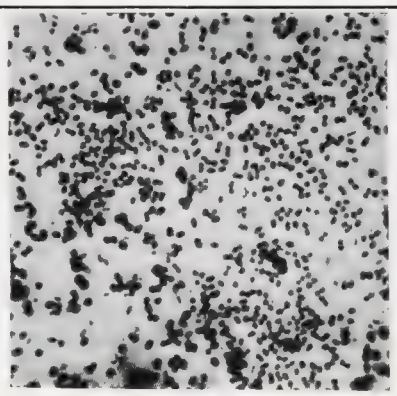

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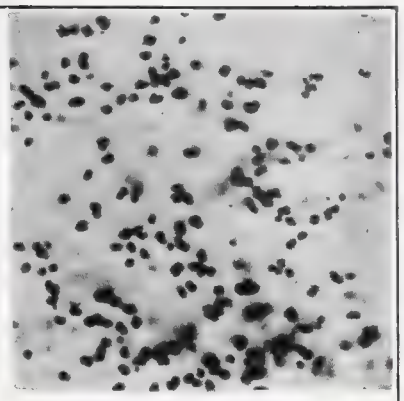

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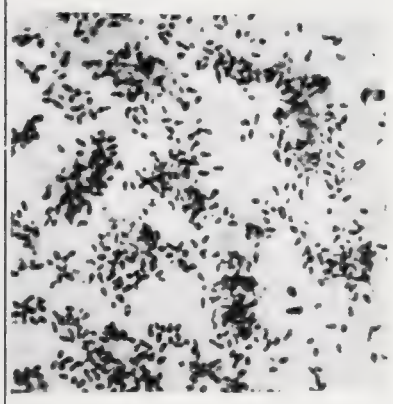

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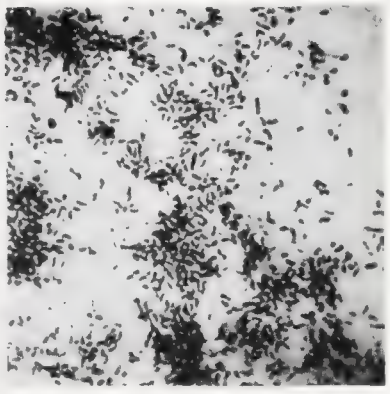

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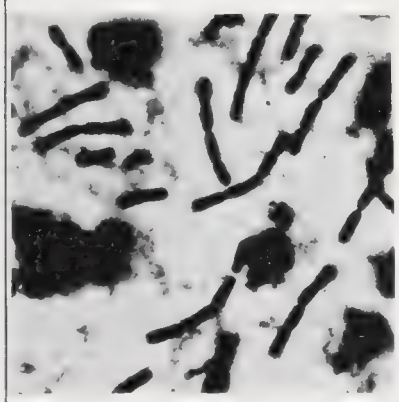

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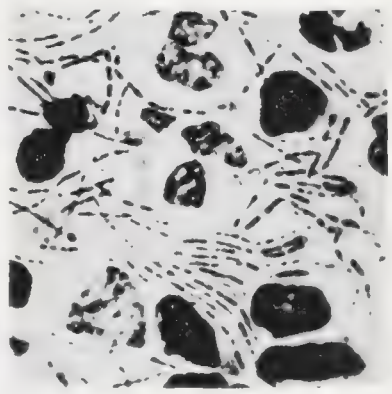

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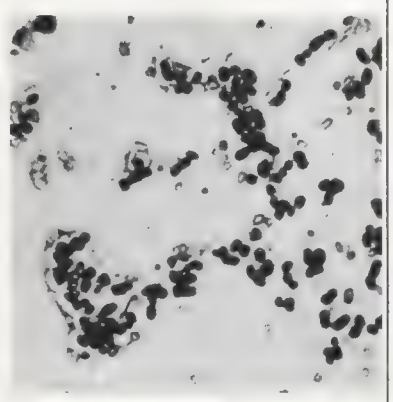

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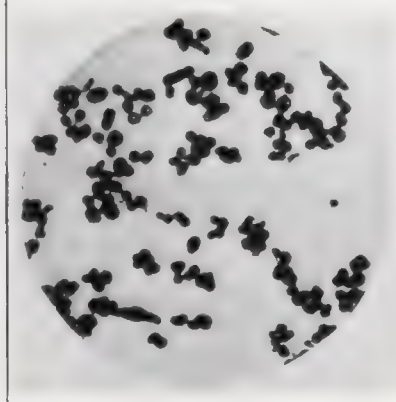

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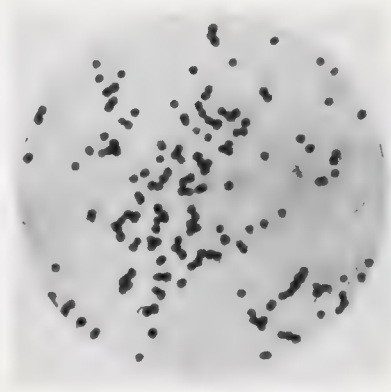

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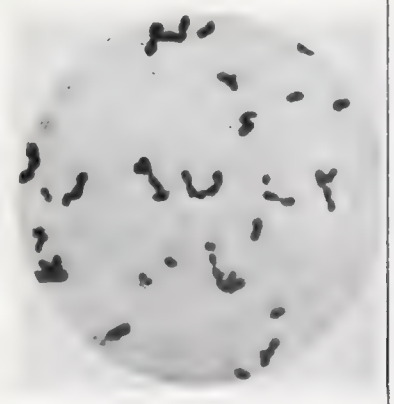

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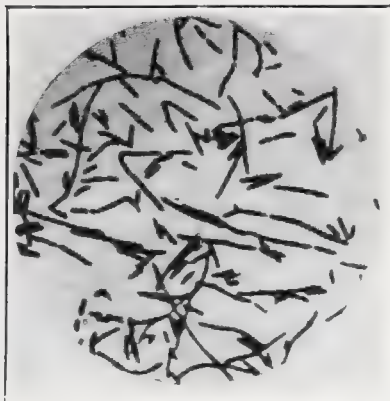
PLATE VI.

FIG. 61. (p. 64): B. anthracis. *Henri* (1914, original fig. 7). ×925.
62. (p. 64): B. anthracis. *Henri* (1914, original fig. 8). ×925.
63. (p. 64): B. anthracis. *Henri* (1914, original fig. 9). ×925.
64. (p. 64): B. subtilis. *Löhnis* and *Smith* (1916 *b*, original fig. 6). ×1,000.
65. (pp. 64, 138): B. subtilis. *Löhnis* and *Smith* (1916*a*, original fig. 26). ×1,000.
66. (p. 64): Bac. aus Hackfleisch. *Maassen* (1904, original fig. XIV, 11). ×1,000.
67. (p. 65): B. malabarensis. *Löhnis* and *Pillai* (1907, original fig. 2). ×1,200.
68. (pp. 65, 134): B. Azotobacter. *Löhnis* and *Hanzawa* (1914, original fig. 28). ×800.
69. (pp. 65, 136): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 20). ×1,000.
70. (pp. 65, 185): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 16). ×1,000.
71. (p. 65): Azotobacter. *Walton* (1915, original fig. I, 9). ×1,000.
72. (p. 65): Azotobacter. *Walton* (1915, original fig. I, 10). ×1,000.



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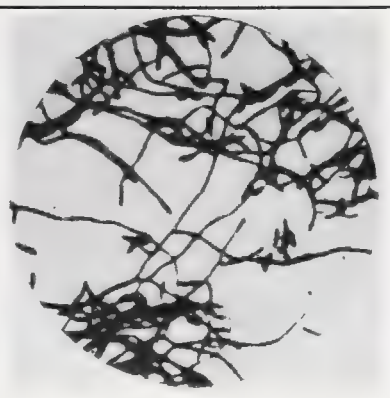

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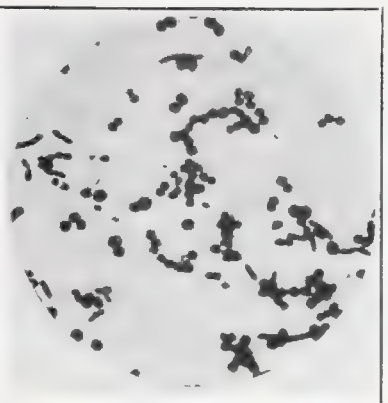

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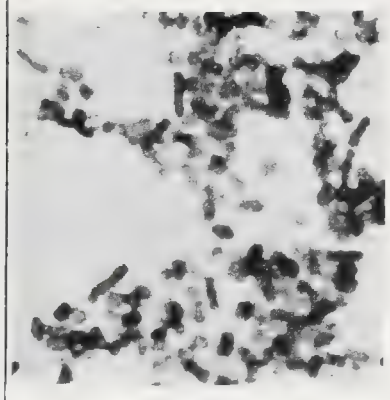

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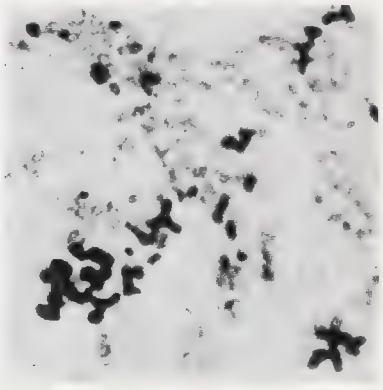

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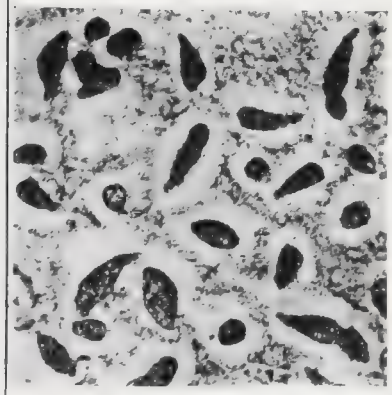

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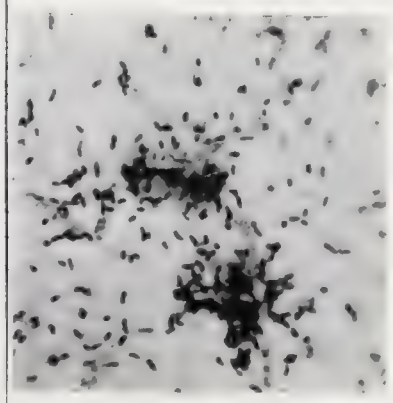

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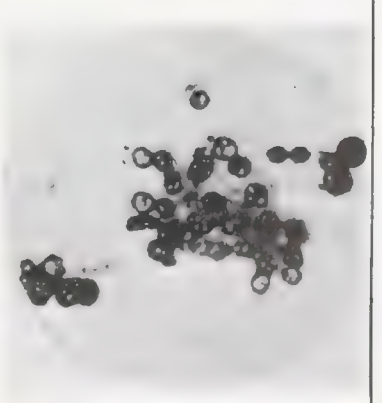

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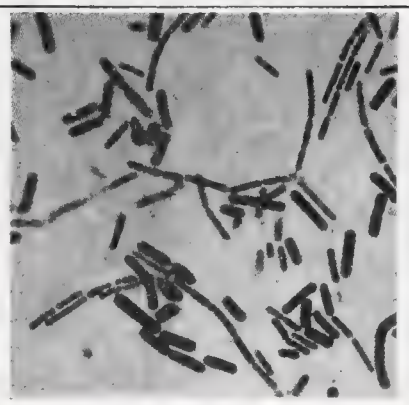
PLATE VII.

FIG. 73. (p. 66): Clostr. Pastorianum. *Winogradsky* (1902, original fig. 3). ×1,000.
74. (p. 67): B. Chauvoei. *Grassberger* (1903, original fig. 54). ×1,000.
75. (p. 67): B. Chauvoei. *Grassberger* (1903, original fig. 21). ×1,000.
76. (p. 67): B. Chauvoei. *Hibler* (1908, original fig. X, 16). ×800(?).
77. (p. 67): B. Chauvoei. *Hibler* (1908, original fig. XVI, 7). ×1,000(?).
78. (p. 67): B. oedematis maligni. *Grassberger* (1903, original fig. 42). ×1,000.
79. (p. 69): V. cholerae. *Fraenkel* und *Pfeiffer* (1895, original fig. 99). ×1,000.
80. (p. 69): V. cholerae. *Itzerott* und *Niemann* (1895, original fig. 53). ×1,000.
81. (p. 70): V. cholerae. *Stamm* (1914, original fig. XI, 2 and 4). ×1,000.
82. (p. 70): V. cholerae. *Stamm* (1914, original fig. XI, 5 and XII, 15). ×1,000.
83. (p. 70): V. cholerae. *Stamm* (1914, original figs. 1 and 2). ×1,000.
84. (p. 72): V. phosphorescens. *Maassen* (1904, original figs. 10 and 3). ×1,000.

73



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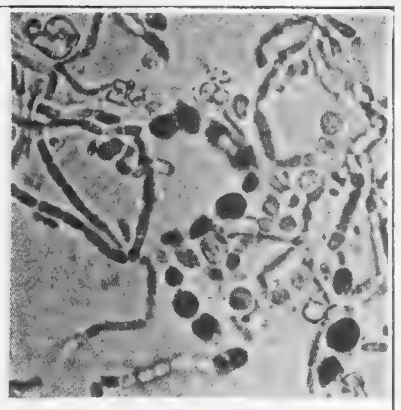

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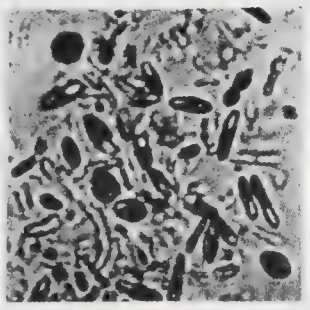

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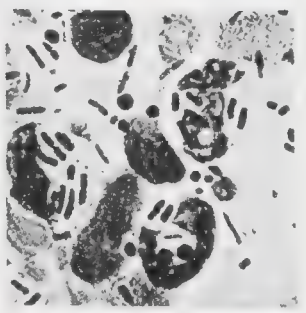

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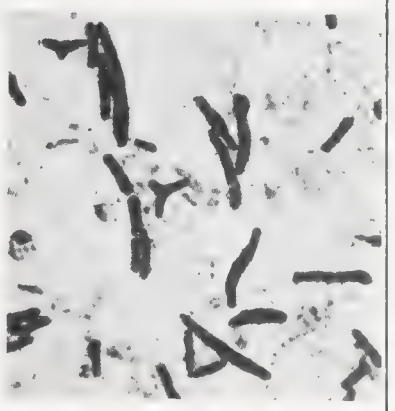

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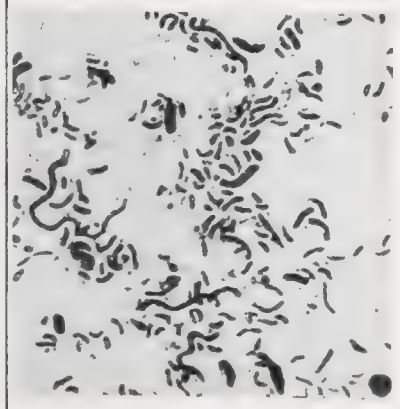

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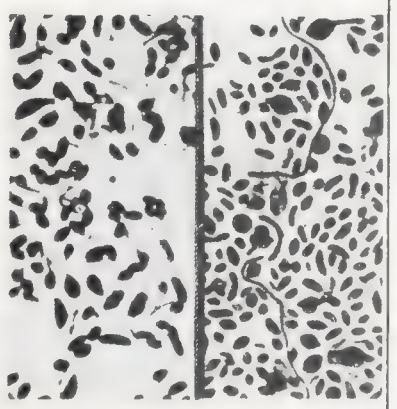

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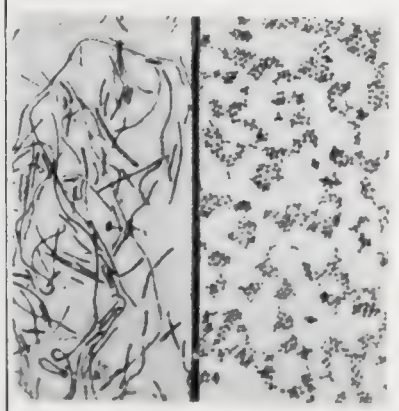

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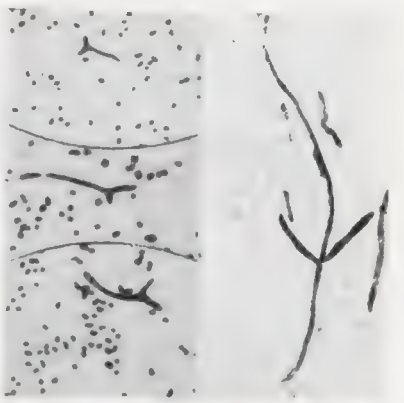

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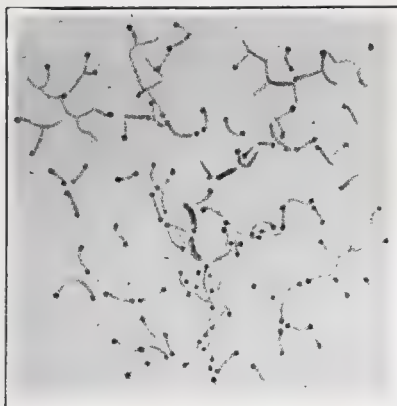
PLATE VIII.

FIG. 85. (p. 72): V. lingualis. *Bajardi* (1903, original fig. 1). ×1,000.
86. (pp. 72, 203): Spirillum rubrum. *Reichenbach* (1901, original fig. 6). ×1,000.
87. (pp. 73, 203): Spirillum rubrum. *Reichenbach* (1901, original fig. 8/9). ×1,000.
88. (p. 73): Spirochaeta pallida. *Meirowsky* (1914 *b*, original fig. XI, 46, 55, and 56). ×2,000–3,000.
89. (pp. 76, 98): Streptothrix cuniculi. *Schmorl* (1891, original fig. 2). ×1,000.
90. (pp. 76, 98): Streptothrix cuniculi. *Schmorl* (1891, original fig. 5). ×1,000.
91. (pp. 77, 134): B. mallei. *Carpano* (1913, original fig. 1). ×1,000.
92. (p. 77): B. mallei. *Carpano* (1913, original fig. 2). ×1,000.
93. (p. 77): B. mallei. *Carpano* (1913, original fig. 3). ×1,000.
94. (p. 77): B. mallei. *Carpano* (1913, original fig. 4). ×1,000.
95. (p. 77): B. mallei. *Carpano* (1913, original fig. 5). ×1,000.
96. (pp. 77, 126): B. mallei. *Carpano* (1913, original fig. 6). ×1,000.



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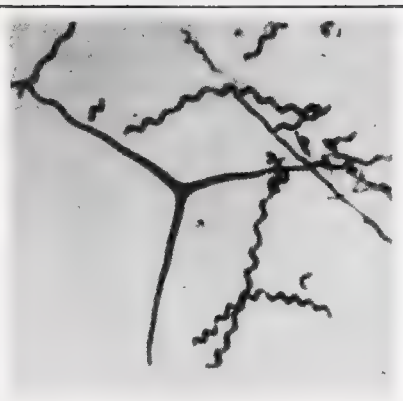

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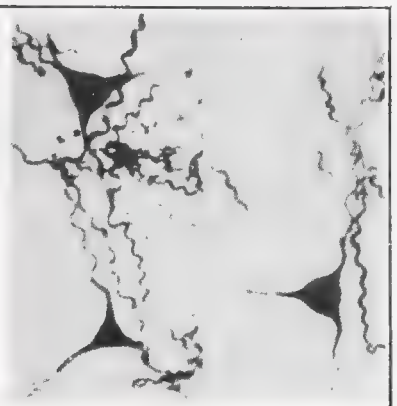

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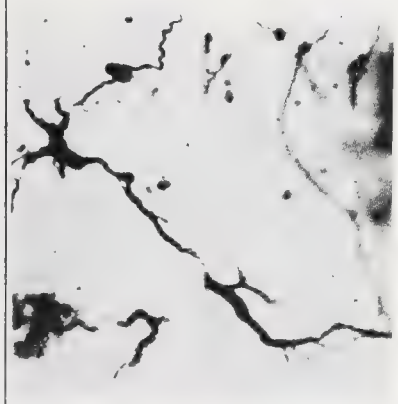

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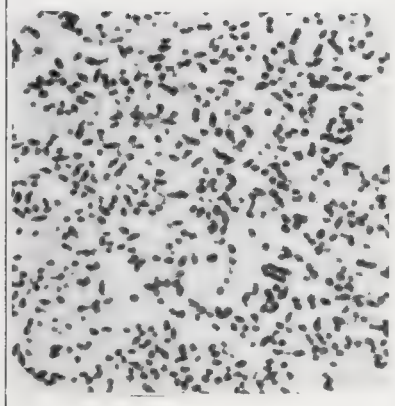

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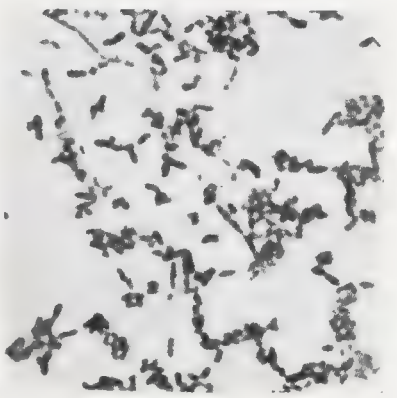

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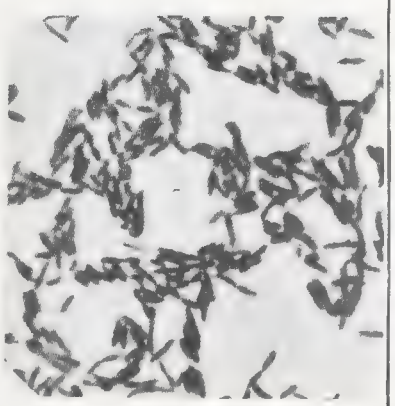

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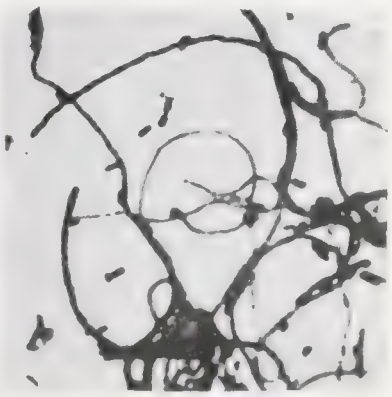

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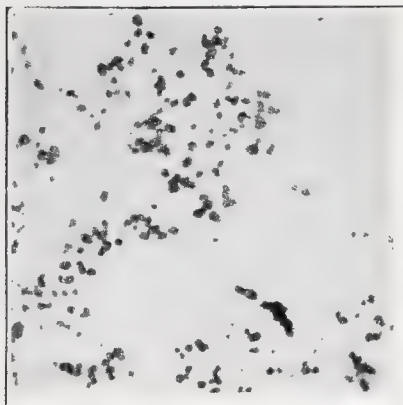
PLATE IX.

FIG. 97. (pp. 79, 134): B. diphtheriae. *J. Dale* (1910, original fig. 6). ×1,000.
98. (pp. 80, 134): B. variabilis. *Nakanishi* (1900 *c*, original fig. 8). ×1,000.
99. (p. 81): Corynebacterium. *E. de Negri* (1916, original fig. 12). ×560.
100. (p. 81): Corynebacterium. *E. de Negri* (1916, original fig. 11). ×560.
101. (pp. 81, 134): Corynebacterium. *E. de Negri* (1916, original fig. 30/73). ×560.
102. (pp. 84, 98): Pia mater tubercul. *Cornil* et *Babes* (1890, original fig. 342). ×500.
103. (pp. 84, 134): Tuberculosis. *Arrigo* (1900, original fig. 1 *a*). ×670.
104. (pp. 84, 134): Tuberculosis. *Arrigo* (1900, original fig. 2 *b*). ×670.
105. (p. 84): B. tuberculosis. *Migula* (1900, v. II, original fig. V, 3). ×1,000.
106. (p. 86): Pseudo-tuberculosis. *Preisz* (1894, original fig. III/IV). ×1,000.
107. (p. 86): Pseudo-tuberculosis. *Preisz* (1894, original fig. V). ×1,000.
108. (p. 86): Actinomyces. *J. Israël* (1878, original fig. II, 4). ×750.



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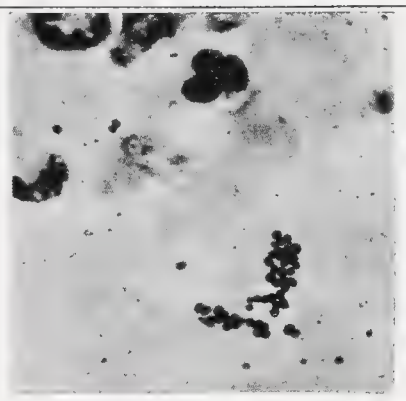

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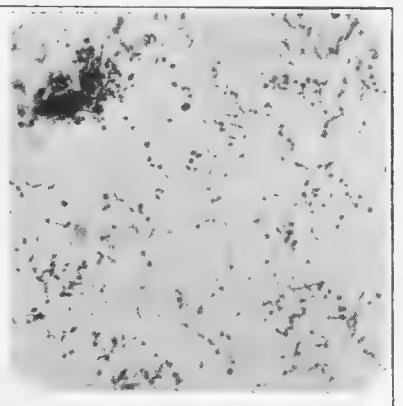

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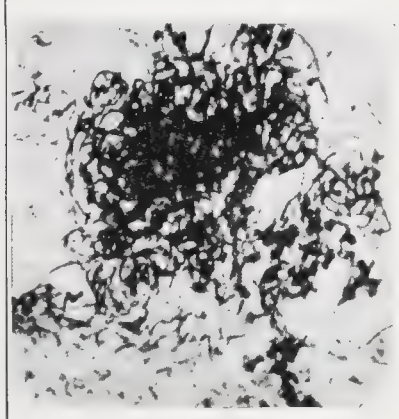

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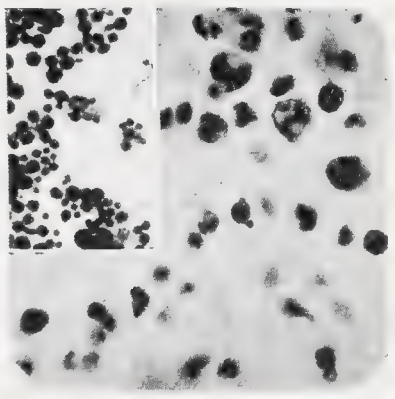

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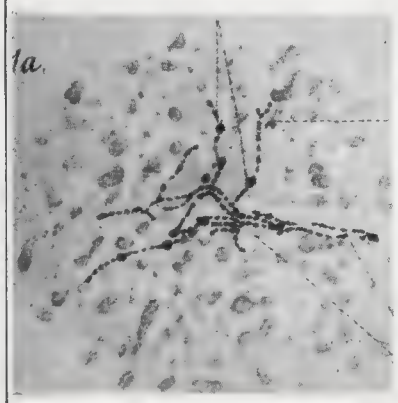

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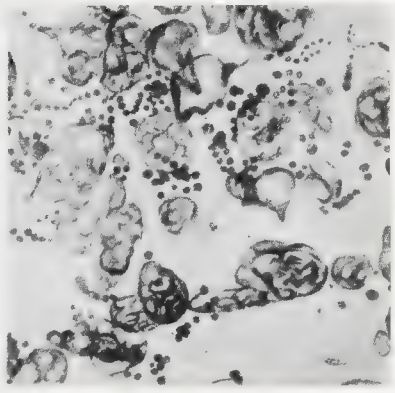

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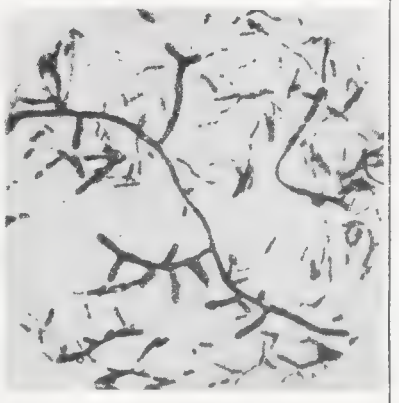

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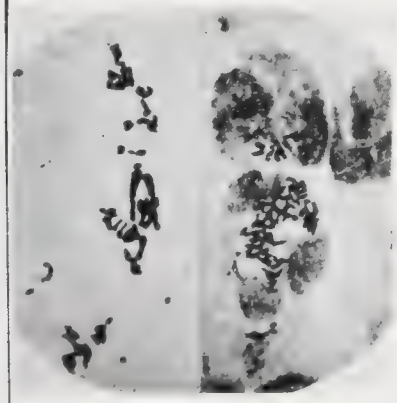

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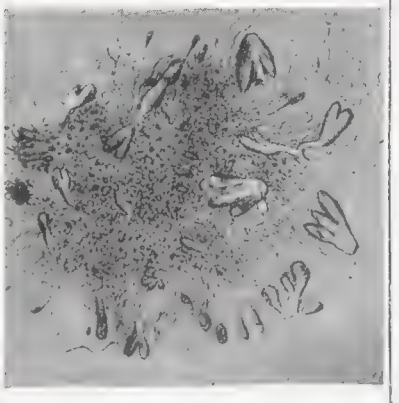

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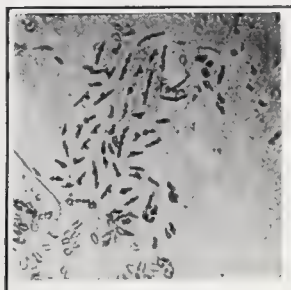
PLATE X.

FIG. 109. (p. 92): B. termo. *R. Koch* (1877, original fig. XV, 4). ×500.
110. (p. 92): B. fluorescens. *Löhnis* and *Smith* (1916 *a*, original fig. 40). ×1,000.
111. (p. 92): B. anthracis. *R. Koch* (1877, original fig. XVI, 5). ×700.
112. (p. 92): B. anthracis. *Günther* (1906, original fig. 29). ×1,000.
113. (p. 94): B. anthracis. *R. Koch* (1881, original fig. VI, 33). ×700.
114. (p. 94): B. oedematis maligni. *R. Koch* (1881, original fig. VIII, 46). ×700.
115. (pp. 95, 126): B. Chauvoei. *Hibler* (1908, original fig. VIII, 18). ×1,900.
116. (pp. 95, 126): B. Chauvoei. *Hibler* (1908, original fig. VIII, 17). ×2,000.
117. (pp. 99, 138): B. Chauvoei. *Fraenkel* und *Pfeiffer* (1895, original fig. 60). ×1,000.
118. (pp. 99, 138): B. pestis. *Maassen* (1904, original fig. X, 4). ×1,000.
119. (pp. 99, 138): B. lact. aërogenes. *Maassen* (1904, original fig. X, 7). ×1,000.
120. (pp. 97, 138): Proteus vulgaris. *Hauser* (1885, original fig. X, 16). ×1,000.
121. (pp. 99, 138): V. cholerae. *Maassen* (1904, original fig. XI, 1). ×1,000.
122. (pp. 96, 126): Pneumococcus. *Artigalas* (1885, original fig. 1, pl. 5).
123. (pp. 97, 153): Proteus hominis capsulatus. *Bordoni-Uffreduzzi* (1888 *b*, original fig. VIII, 6). ×750.
124. (p. 98): V. cholerae. *Cornil* et *Babes* (1890, original fig. 275). ×1,500.
125. (p. 99): B. pyocyaneus. *Matzuschita* (1900, original fig. 26). ×1,000.
126. (p. 99): Spirilla. *Itzerott* und *Niemann* (1895, original fig. II, 7). ×1,000.
127. (p. 99): B. anthracis. *Itzerott* und *Niemann* (1895, original fig. III, 16). ×1,000.
128. (p. 99): B. capsulatus. *Itzerott* und *Niemann* (1895, original fig. VIII, 46). ×1,000.
129. (p. 99): V. Bonhoff. *Itzerott* und *Niemann* (1895, original fig. X, 60). ×1,000.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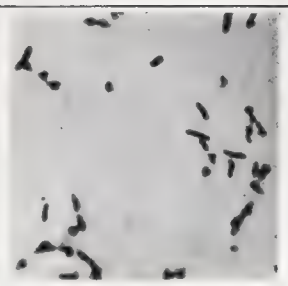
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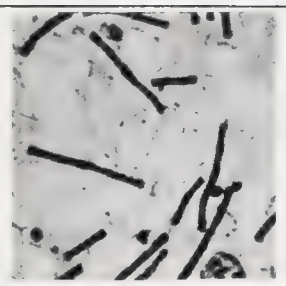
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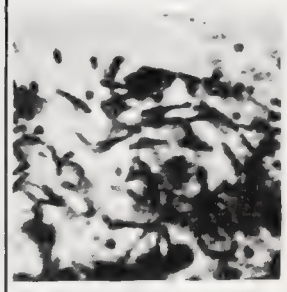
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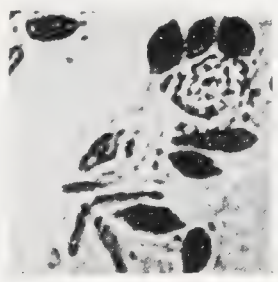
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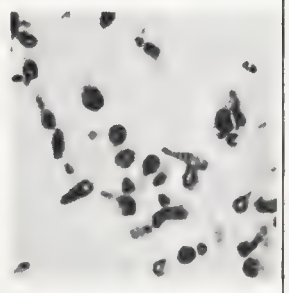
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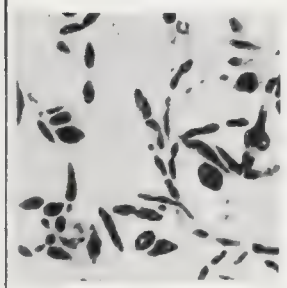
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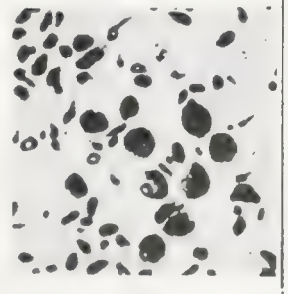
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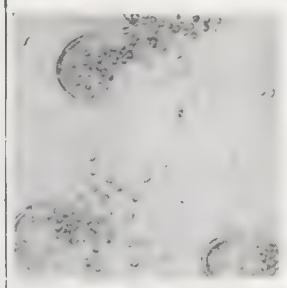
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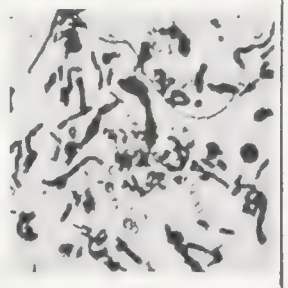
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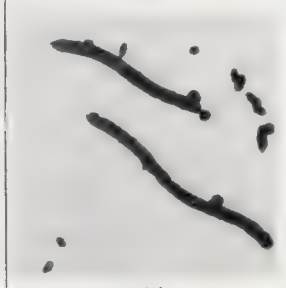
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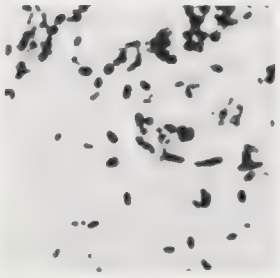
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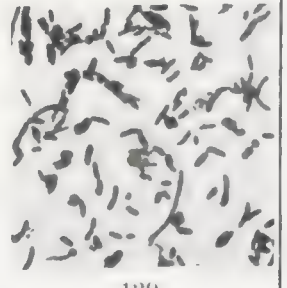
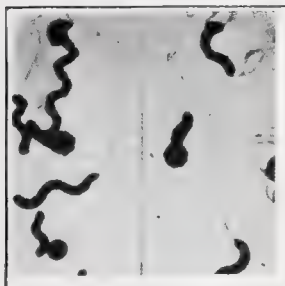

129

PLATE XI.

FIG. 130. (p. 99): Spirillum rubrum. *Itzerott* und *Niemann* (1895, original fig. XVIII, 104). ×1,000.
131. (p. 99): Bacillus sp. *Zettnow* (1891, original fig. 14). ×1,650.
132. (p. 99): Spirillum Undula. *Zettnow* (1896, original fig. 16). ×1,125.
133. (p. 100): Spirillum sp. *Migula* (1904, original fig. II, 8). ×1,000.
134. (p. 100): B. proteus. *Migula* (1904, original fig. II, 4). ×1,000.
135. (pp. 101, 202): B. typhi. *Almquist* (1916, original fig. 4). ×1,000.
136. (p. 101): B. typhi. *Almquist* (1916, original fig. 5). ×1,000.
137. (p. 101): B. dysenteriae. *Almquist* (1916, original fig. 23). ×1,000.
138. (pp. 101, 202): B. typhi. *Almquist* (1917, original fig. 1). ×1,000.
139. (pp. 101, 202): V. cholerae. *Almquist* (1917, original fig. 4). ×1,000.
140. (pp. 101, 202): V. cholerae. *Friedrich* (1892, original fig. V, 4). ×800.
141. (p. 101): B. pyocyaneus. *Muir* and *Ritchie* (1903, original fig. 69). ×1,000.
142. (p. 101): B. enteritititidis. *Günther* (1906, original fig. 54). ×1,000.
143. (p. 101): B. ochraceus. *Migula* (1900, original fig. XI, 3). ×1,000.
144. (p. 101): Spirillum sporiferum. *Migula* (1900, original fig. XVII, 5). ×1,000.
145. (p. 101): B. phlegmasiae uberis. *Kitt* (1899, original fig., p. 393). ×1,000.
146. (pp. 102, 134): Streptoc. lanceolatus. *Axelrad* (1903, original fig. 4). ×1,000.
147. (pp. 102, 134): B. coli. *Axelrad* (1903, original fig. 19). ×1,000.
148. (pp. 103, 153): B. bulgaricus. *Löhnis* and *Smith* (1916 *a*, original fig. 29). ×1,000.
149. (p. 103): Bac. aus Hackfleisch. *Maassen* (1904, original fig. XI, 4). ×1,000.
150. (pp. 103, 202): B. subtilis. *Hiss* and *Zinsser* (1914, original fig. 125).
151. (p. 104): B. Chauvoei. *Grassberger* (1903, original fig. 67). ×1,000.
152. (p. 104): Clostridium Pastorianum. *Winogradsky* (1902, original fig. 1). ×1,000.
153. (p. 105): B. leprae. *Kedrowski* (1910, original fig. 38 *a*). ×1,000.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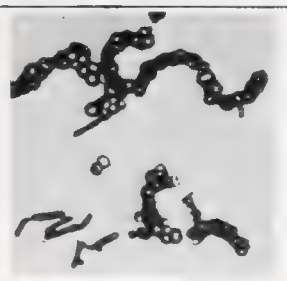
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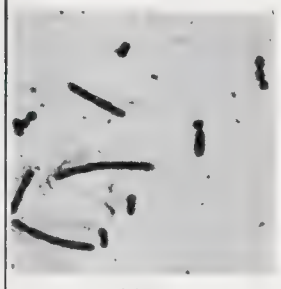
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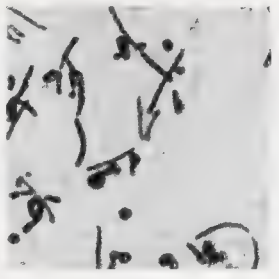
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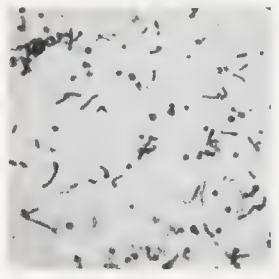
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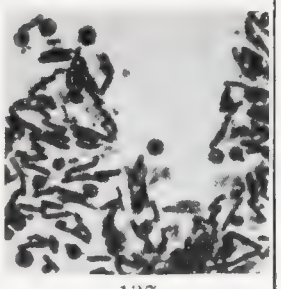
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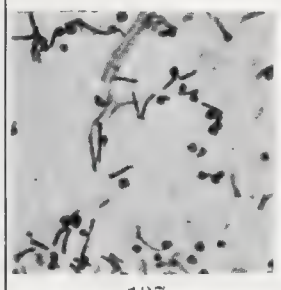
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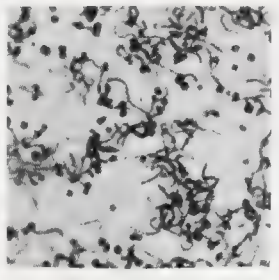
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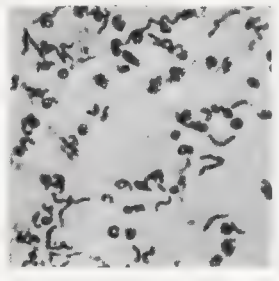
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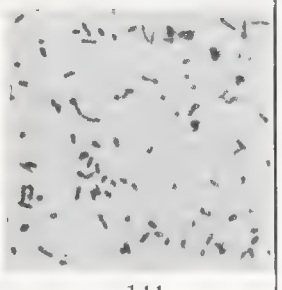
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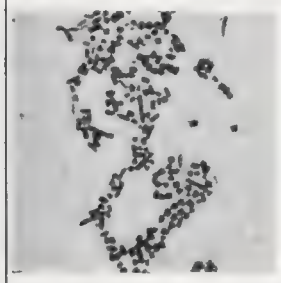
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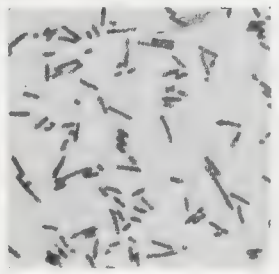
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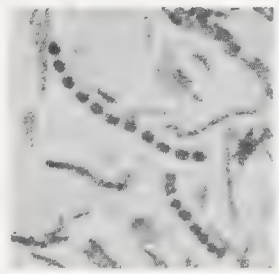
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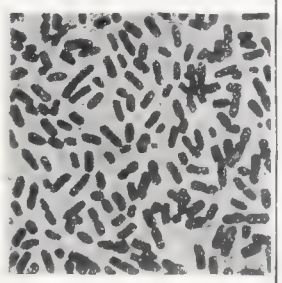
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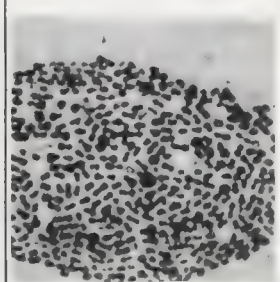
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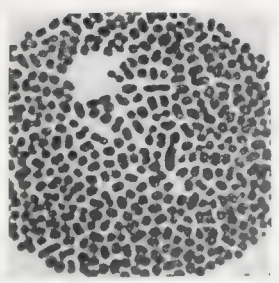
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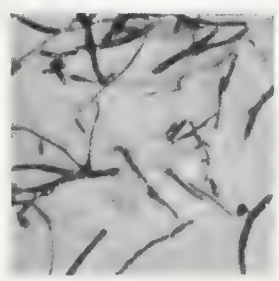
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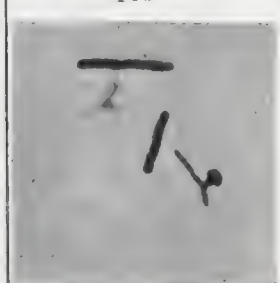
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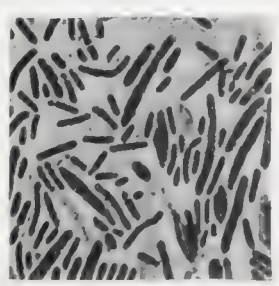
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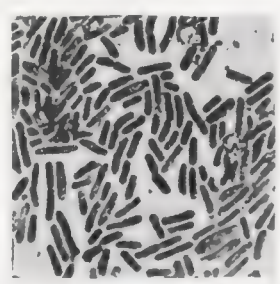
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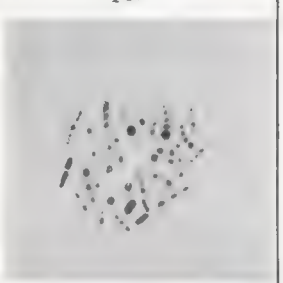
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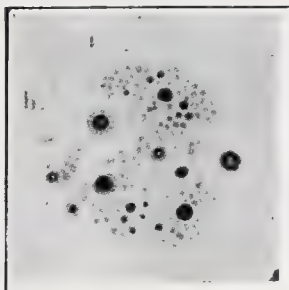
PLATE XII.

FIG. 154. (pp. 105, 134): B. leprae. *Kedrowski* (1910, original fig. 38 *b*). ×1,000.
155. (pp. 105, 134): Meningitis. *Ghon, Mucha* und *Müller* (1906, original fig. 3). ×1,000.
156. (pp. 105, 134): Meningitis. *Ghon, Mucha* und *Müller* (1906, original fig. 18). ×1,000.
157. (pp. 105, 134): B. cyanogenes. *Neelsen* (1880, original fig. XI, 9). ×650.
158. (pp. 105, 134): V. cholerae. *Hammerl* (1906, original fig. 4). ×1,000.
159. (p. 106): B. fusiformis (?). *Rosenow* and *Tunnicliff* (1912, original fig. I, 3). ×750.
160. (p. 106): B. Azotobacter. *D. H. Jones* (1913, original fig. V, 9/10. ×1,000.
161. (p. 106): B. subtilis. *Marrassini* (1913, original fig. I, 28). ×1,000.
162. (p. 107): B. tuberculosis. *Meirowsky* (1914 *b*, original Pl. II *a*). ×2,000.
163. (p. 107): B. tuberculosis. *Meirowsky* (1914 *b*, original Pl. II *a*). ×2,000.
164. (pp. 107, 135): B. tuberculosis. *Meirowsky* (1914 *b*, original Pl. II *a*). ×2,000.
165. (p. 107): B. leprae. *Meirowsky* (1914 *b*, original Pl. II *b*). ×2,000.
166. (pp. 107, 135): B. leprae. *Meirowsky* (1914 *b*, original Pl. II *b*). ×2,000.
167. (pp. 107, 135): Spirillum rubrum. *Meirowsky* (1914 *b*, original Pl. V *a*). ×2,000.
168. (pp. 108, 151): M. candicans. *Löhnis* and *Smith* (1916 *b*, original fig. 31). ×1,000.
169. (pp. 108, 124): M. luteus. *Löhnis* and *Smith* (1916 *b*, original fig. 32). ×1,000.
170. (pp. 108, 132): Streptoc. lactis. *Löhnis* and *Smith* (1916 *b*, original fig. 30). ×1,000.
171. (pp. 108, 153): B. pneumoniae. *Löhnis* and *Smith* (1916 *b*, original fig. 37). ×1,000.
172. (pp. 108, 153): B. bulgaricus. *Löhnis* and *Smith* (1916 *b*, original fig. 36). ×1,000.
173. (p. 108): Azotob. Beijerinckii. *Löhnis* and *Smith* (1916 *b*, original fig. 33). ×1, 000.
174. (p. 108): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 28). ×1,000.
175. (p. 108): Az. vinelandii. *Löhnis* and *Smith* (1916 *a*, original fig. 24). ×1,000.
176. (pp. 108, 129): Az. chroococcum. *Löhnis* and *Smith* (1916 *b*, original fig. 26). ×1,000.
177. (p. 108): Bacillus sp. *Goadby* (1917, original fig. 14). ×1,000.



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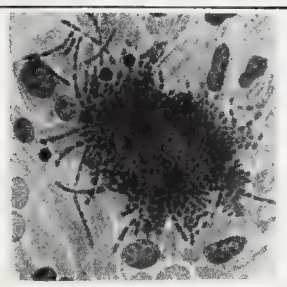

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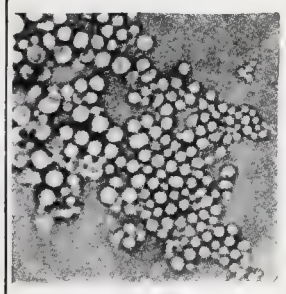

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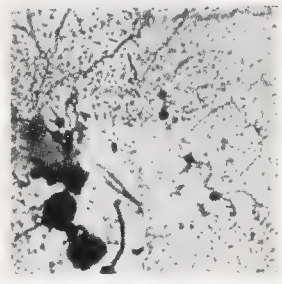

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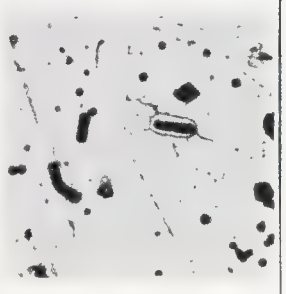

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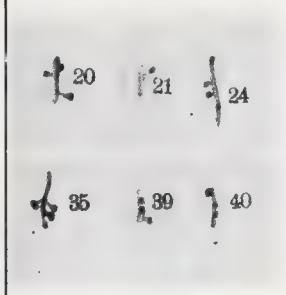

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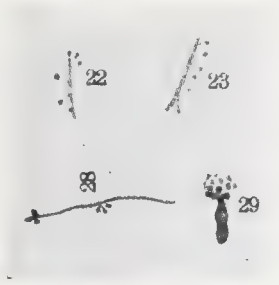

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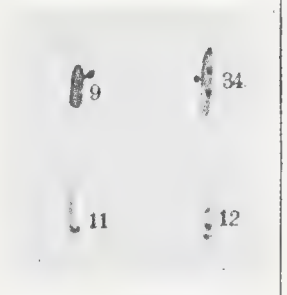

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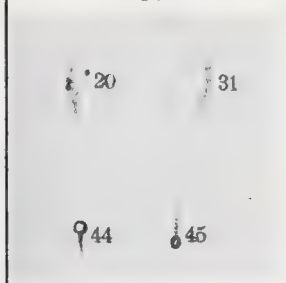

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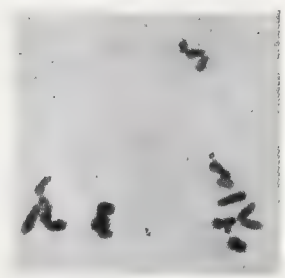

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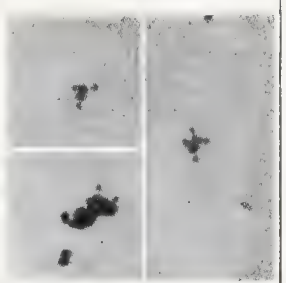

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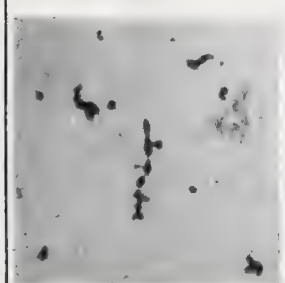

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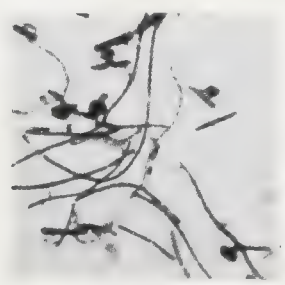

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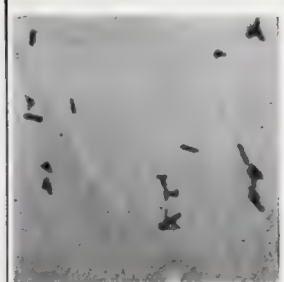

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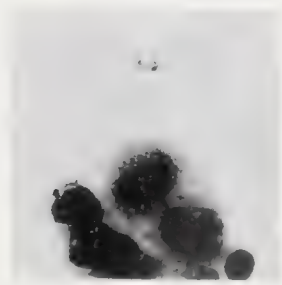

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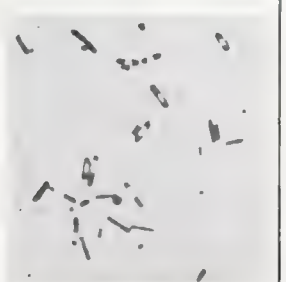

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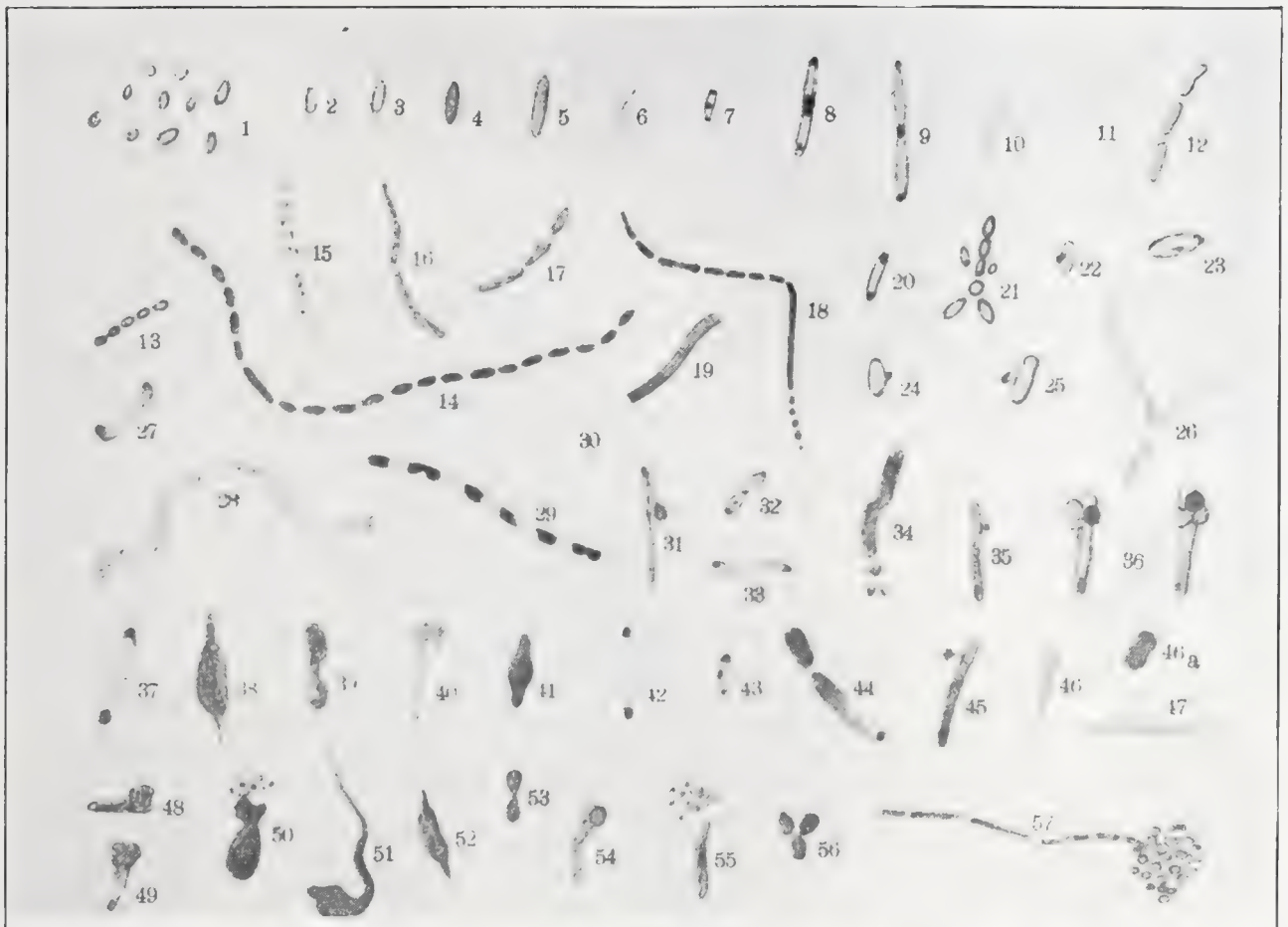
PLATE XIII.

Fig. 178. (pp. 108, 192): B. paratyphi B. *Meirowsky* (1914 *b*, original Pl. III). ×2,000.
179. (pp. 108, 127): B. typhosus. *Hort* (1917 *a*, original fig. 1). × 1,500.
180. (pp. 108, 127): B. coli. *Hort* (1917 *a*, original fig. 2). × 1,500.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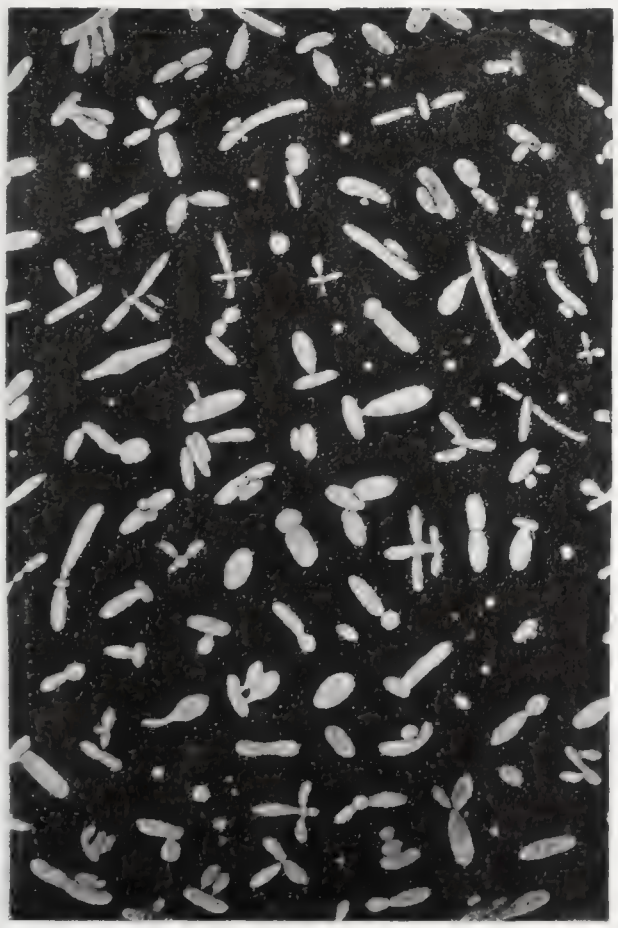

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PLATE XIV.

(pp. 107, 128, 158, 177): Budding and branching of bacteria. *Meirowsky* (1914 *b*, original Pl. XVIII). ×2,000.

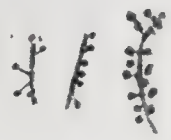
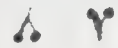
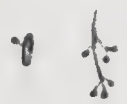
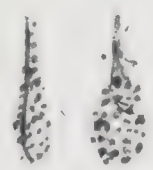
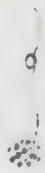
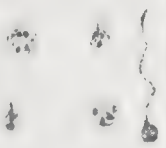
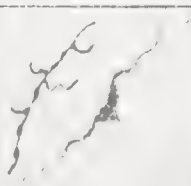
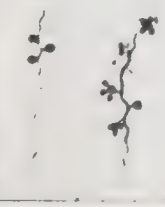
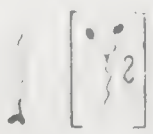
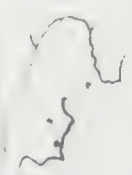
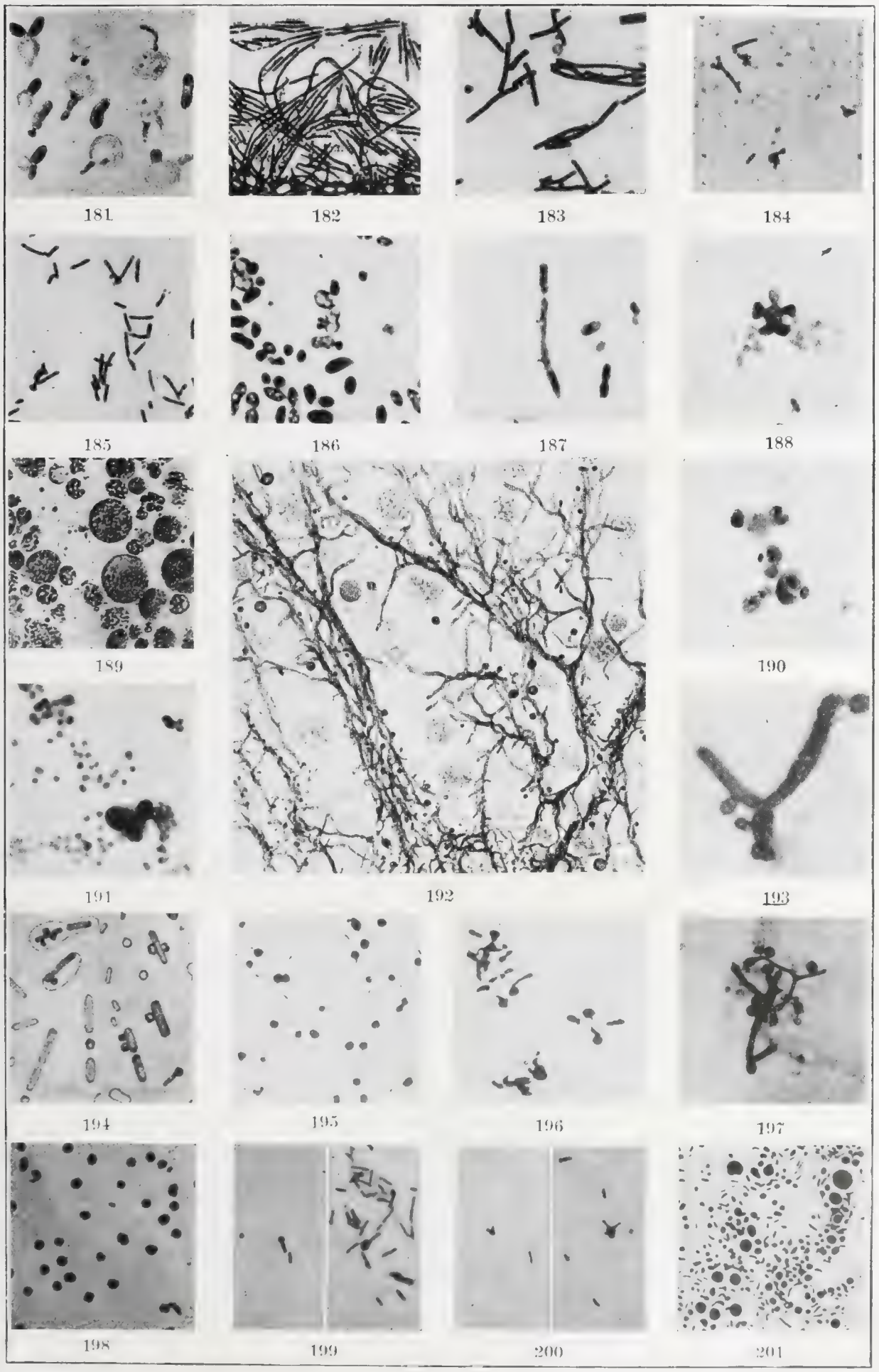
	Seiten- und endständige Knospen	Dolden-bildung	Freie Knospen und Jugend-formen	Teilung der Knospen und Längsspaltg.	Seiten-sprossung
Tubercul. hum. Reinkultur					
Tubercul. bov. Reinkultur					
Leprabazillen aus einem Leprom nach Behandlung mit 10 % Antiformin					
Paratyphus B. Reinkultur					
Gärtner'sche Enteritisbazillen Reinkultur					
Spirochaeta gallinar.					
Mundspirochäten (Stomatitis mercur.)					
Spirill. rubr.					
Spirochaeta pallida Reinkultur					

PLATE XV.

FIG. 181. (p. 117): Plasmoptysis. *A. Fischer* (1906, original fig. III, 8). ×1,500.
182. (p. 124): B. coli. *Kellerman* and *Scales* (1916, original fig. 24). ×1,000.
183. (p. 124): Bac. no. 41. *Löhnis* and *Smith* (1916 *a*, original fig. 39). ×1,000.
184. (p. 128): Corynebacterium. *E. de Negri* (1916, original fig. 27) ×560.
185. (pp. 128, 202): B. coli. *Kellerman* and *Scales* (1916, original fig. 23). ×1,000.
186. (p. 128): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 3). ×1,000.
187. (p. 128): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 4). ×1,000.
188. (p. 128): *B.* Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 1). ×1,000.
189. (p. 126): Az. chroococcum. *Beijerinck* (1901 *b*, original fig. 4). ×1,000.
190. (p. 129): Az. vitreum. *Löhnis* and *Smith* (1916 *a*, original fig. 6). ×1,000.
191. (p. 127): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 5). ×1,000.
192. (pp. 126, 194): "Phthisiogenic microbe." *Schroen* (1904, original fig. VIII). ×500.
193. (p. 129): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 21). ×1,000.
194. (p. 132): "Syphilis Bacillus." *Niessen* (1898, original fig. 13). ×900.
195. (p. 132): B. radicicola. *Hilter* und *Störmer* (1903, original fig. II, 1). ×1,000.
196. (p. 132): B. radicicola. *Hilter* und *Störmer* (1903, original fig. II, 2). ×1,000.
197. (pp. 132, 136): B. subtilis. *Löhnis* and *Smith* (1916 *b*, original fig. 27). ×1,000.
198. (p. 135): Nitrosococcus. *Winogradsky* (1891, original fig. XVIII, 2). ×1,000.
199. (p. 135): B. coli. *Kellerman* and *Scales* (1916, original figs. 19 and 20). ×1,000.
200. (p. 135): B. coli. *Kellerman* and *Scales* (1916, original figs. 21 and 22). ×1,000.
201. (p. 135): V. cholerae. *Stamm* (1914, original fig. 20). ×1,000.



181 182 183 184

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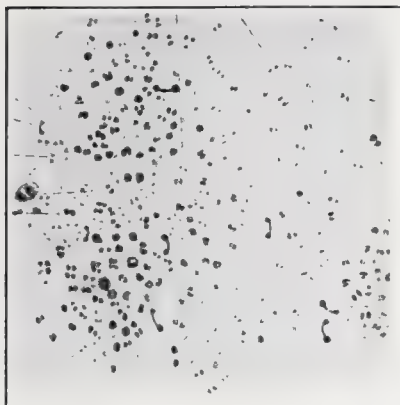
PLATE XVI.

Fig. 202. (p. 145): Microc. gonorrhoeae. *Herzog* (1913, original fig. III, 5). ×1,000.
203. (p. 149): Hematocyts. *Fokker* (1887, original fig. I, 1). ×770.
204. (p. 149): Bacilli from blood. *Fokker* (1888, original fig. III, 2). ×770.
205. (p. 168): Zoogloea with embryonal areas. *Bastian* (1905, original fig. 12). ×500.
206. (p. 168): Regeneration of cells. *Bastian* (1905, original fig. 11, B/C). ×500.
207. (p. 168): Zoogloea in transformation. *Bastian* (1905, original fig. 13). ×750.
208. (p. 168): Cell formation. *Bastian* (1907, original fig. 33). ×500.
209. (p. 170): Macroplasts of B. rubescens. *Lankester* (1876, original fig. III, 8, 9, 15, 20). ×1,100.



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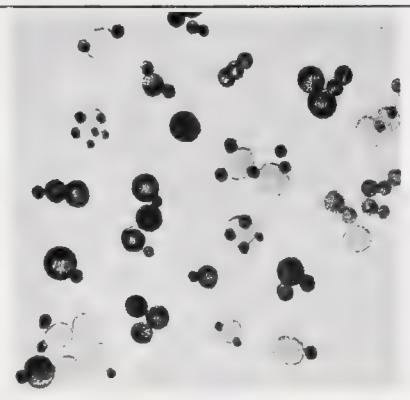

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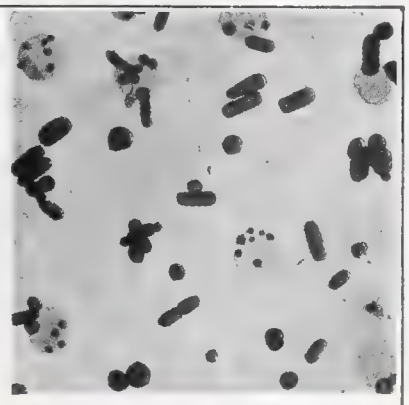

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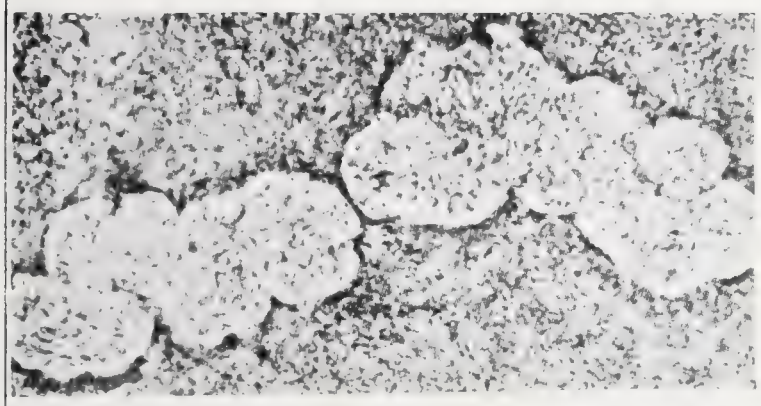

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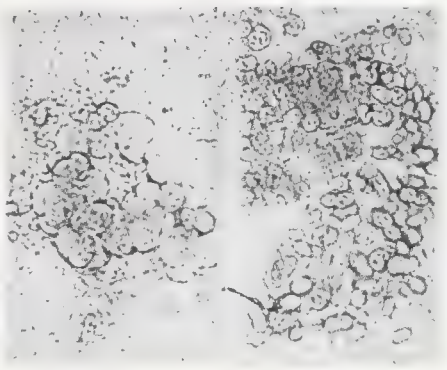

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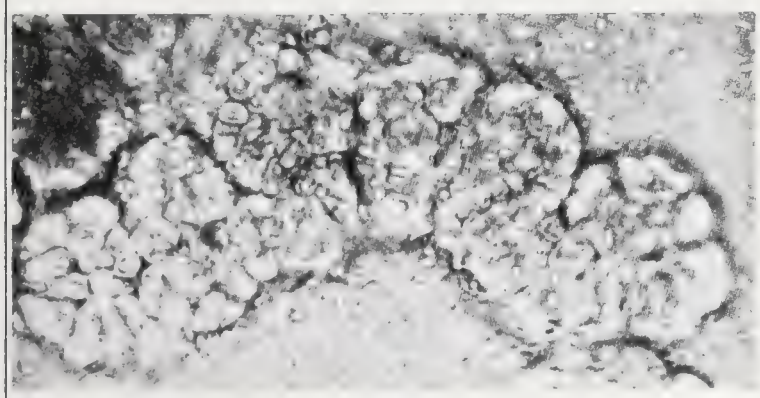

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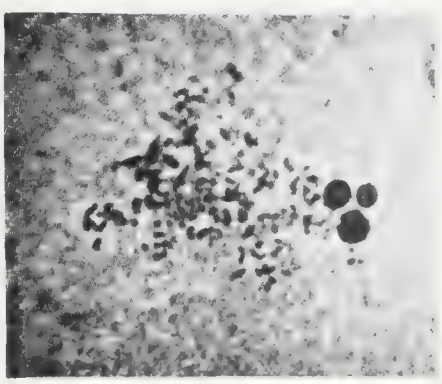

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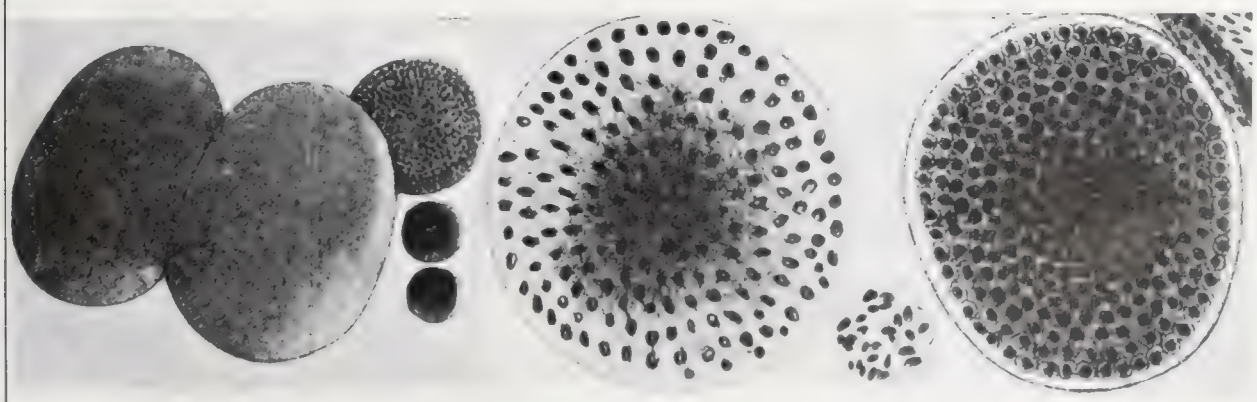

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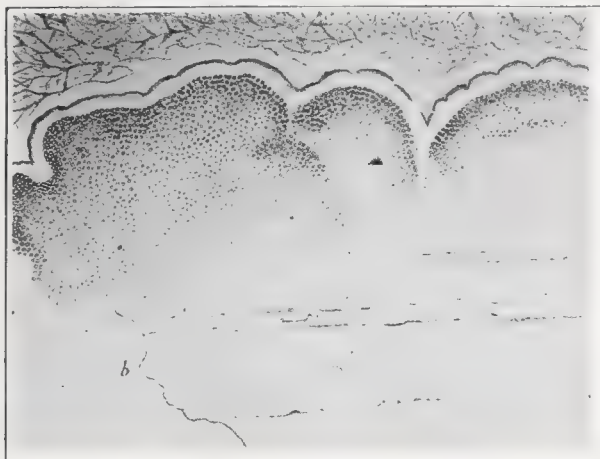
PLATE XVII.

FIG. 210. (p. 169): Endocarditis. Klebs (1878, original fig. II, 3).
211. (p. 171): Septicaemia. *R. Koch* (1878, original fig. I, 8) ×700.
212. (p. 175): Plasmodia and filidia. *W. Winkler* (1899, original figs. 13, 15, 16, 34, 35, 40, 41, 48, 50) ×800–1,000.
213. (p. 176): Actinobacillosis. *Lignières* et *Spitz* (1902, original fig. 3 A and B).



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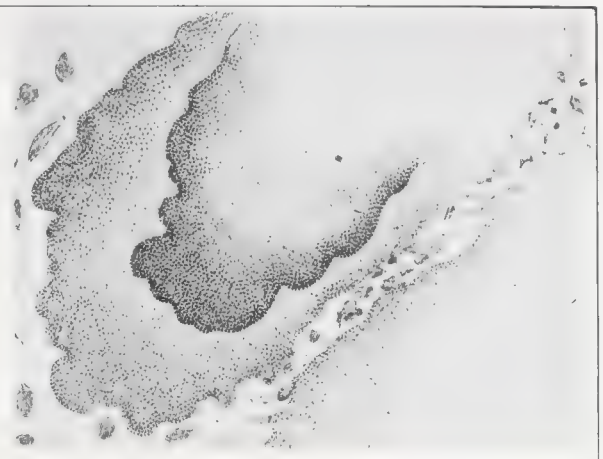

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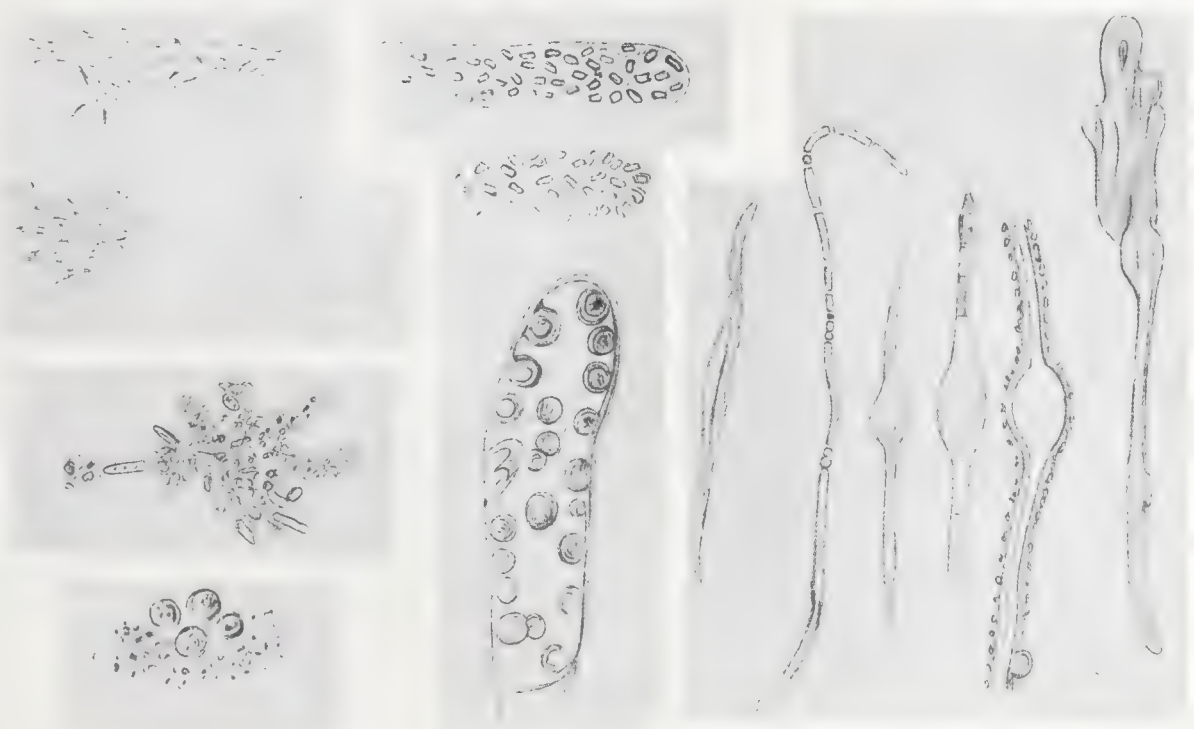

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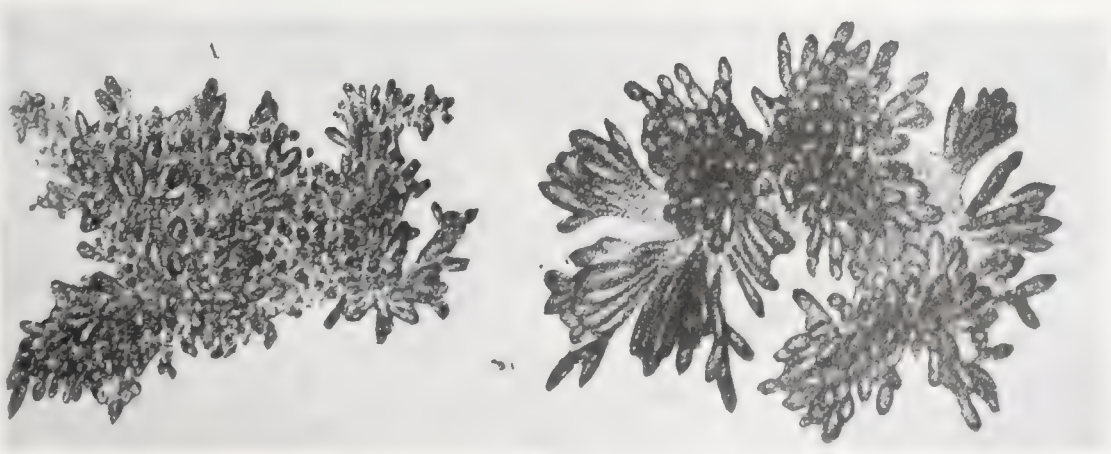

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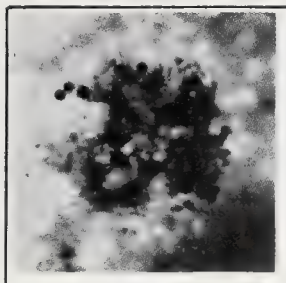
PLATE XVIII.

FIG. 214. (pp. 172, 191): Str. lactis. *Löhnis* and *Smith* (1916 *a*, original fig. 33). ×1,000.
215. (pp. 175, 191): Str. lactis. *Löhnis* and *Smith* (1916 *a*, original fig. 32). ×1,000.
216. (pp. 175, 190): M. candicans. *Löhnis* and *Smith* (1916 *b*, original fig. 56). ×1,000.
217. (pp. 175, 190): "Syphilis Bacillus." *Niessen* (1898, original fig. 13). ×900.
218. (p. 176): B. pestis. *N. K. Schultz* (1901 *a*, original fig. VII). ×1,000.
219. (p. 176): B. pestis. *N. K. Schultz* (1901 *a*, original fig. VIII). ×1,000.
220. (p. 176): B. pestis. *N. K. Schultz* (1901 *a*, original fig. IX). ×1,000.
221. (p. 176): B. pestis. *N. K. Schultz* (1901 *a*, original fig. XII). ×1,000.
222. (p. 176): Pasteuria ramosa. *Metchnikoff* (1888 *b*, original fig. III). ×850.
223. (pp. 177, 186): B. coli. *Kellerman* and *Scales* (1916, original fig. 29). ×1,000.
224. (pp. 177, 192): B. coli. *Kellerman* and *Scales* (1916, original fig. 7). ×1,000.
225. (pp. 178, 182): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 9). ×1,000.
226. (pp. 178, 182): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 7). ×1,000.
227. (pp. 178, 182): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 41). ×1,000.
228. (pp. 178, 182): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 8). ×1,000.
229. (pp. 178, 182): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 11). ×1,000.
230. (pp. 178, 182): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 43). ×1,000.
231. (pp. 178, 182): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 12). ×1,000.
232. (p. 178): B. fluorescens. *Löhnis* and *Smith* (1916 *a*, original fig. 30). ×1,000.
233. (p. 178): B. subtilis. *Löhnis* and *Smith* (1916 *a*, original fig. 27). ×1,000.
234. (p. 184): B. fluorescens. *Löhnis* and *Smith* (1916 *a*, original fig. 42). ×1,000.
235. (p. 185): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 17). ×1,000.
236. (p. 192): Alnus nodule. *Hiltner* und *Störmer* (1903, original fig. II, 8). ×1,000
237. (p. 179): Granulom. *E. de Negri* (1916, original fig. 62). ×560.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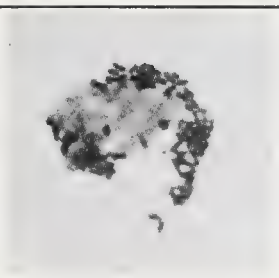
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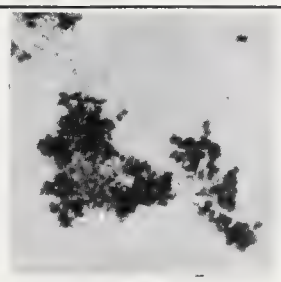
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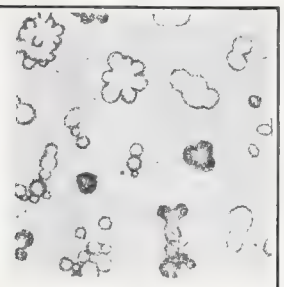
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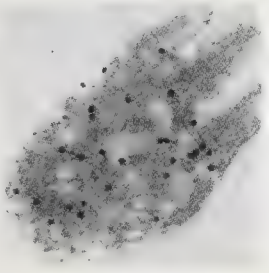
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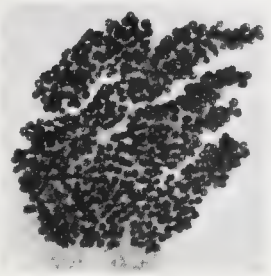
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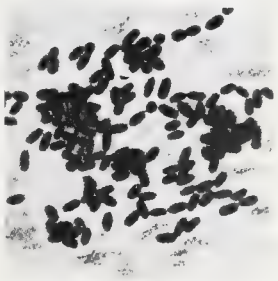
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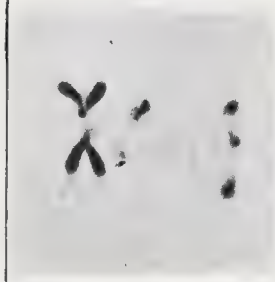
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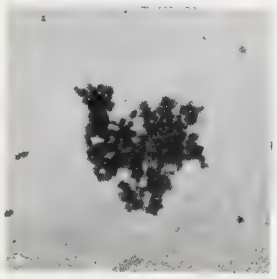
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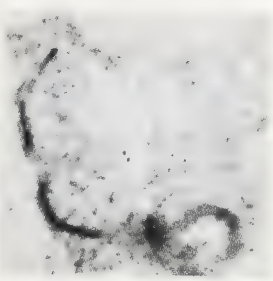
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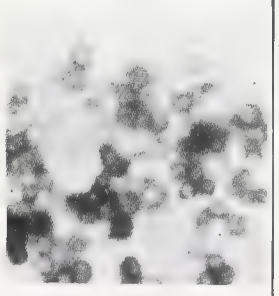
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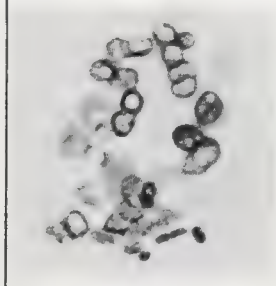
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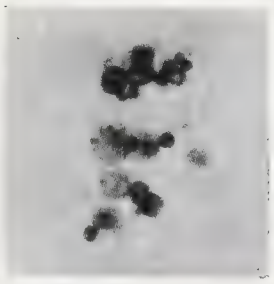
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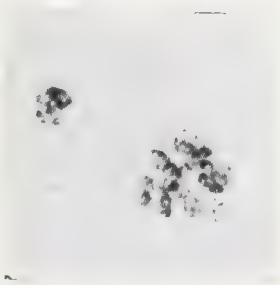
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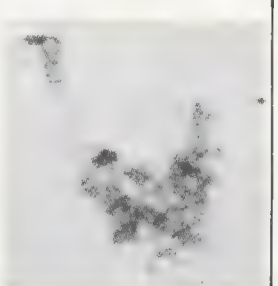
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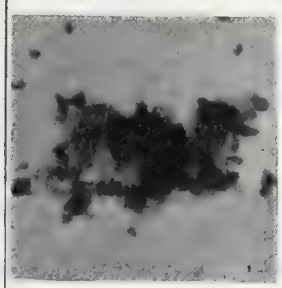
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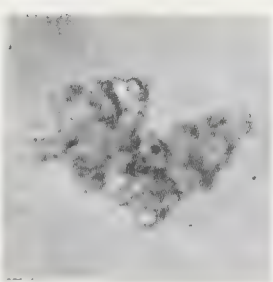
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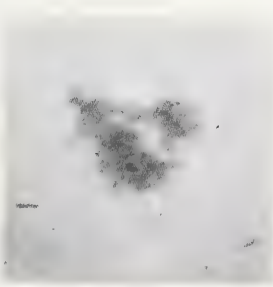
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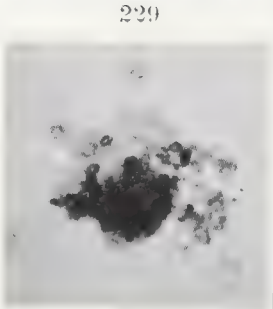
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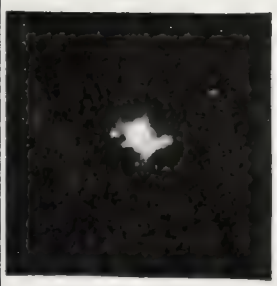
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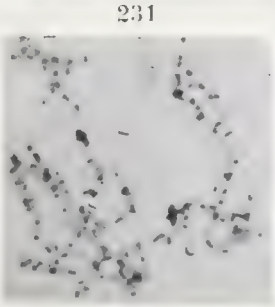
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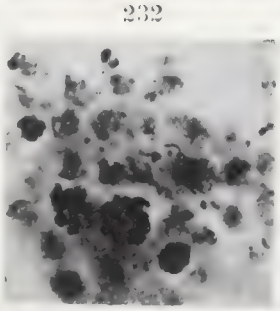
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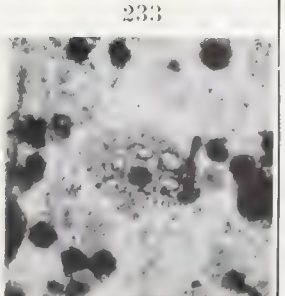
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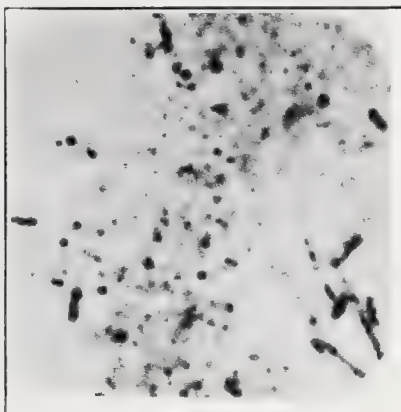
PLATE XIX.

FIG. 238. (pp. 176, 193): Ps. cerevisiae. *Fuhrmann* (1908, original. fig. I, 5). ×1,800.
239. (pp. 176, 181): B. erysipeloides. *Rosenbach* (1909, original fig. XIV, 6). ×970.
240. (pp. 176, 186): B. erysipeloides. *Rosenbach* (1909, original fig. XII, 2). ×970.
241. (p. 176): B. erysipeloides. *Rosenbach* (1909, original fig. XIII, 2). ×970.
242. (pp. 176, 181): B. erysipeloides. *Rosenbach* (1909, original fig. XII, 1). ×270.
243. (pp. 177, 187): B. typhi. *Almquist* (1916, original fig. 12). ×1,000.
244. (pp. 177, 193): V. cholerae. *Almquist* (1916, original fig. 22). ×1,000.
245. (pp. 177, 194): B. diphtheriae. *Almquist* (1917, original fig. 5). ×1,000.
246. (pp. 177, 192): B. acidi propionici c. *Almquist* (1917, original fig. 6). ×1,000.
247. (pp. 177, 184): Bact. antityphosum. *Almquist* (1917, original fig. 12). ×1,000.
248. (pp. 179, 184): Clumps from tonsils. *Mallory* and *Medlar* (1916, original fig. XX, 23). ×1,000.
249. (pp. 179, 194): Diphtheroids from lung. *Mellon* (1917, original fig. 5, pl. 2).



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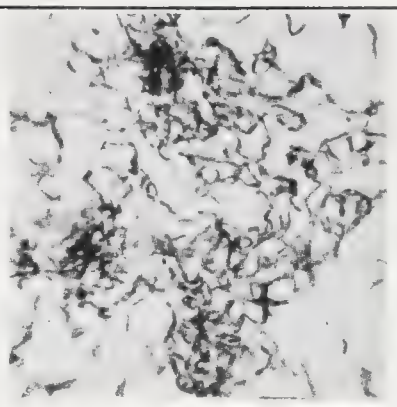

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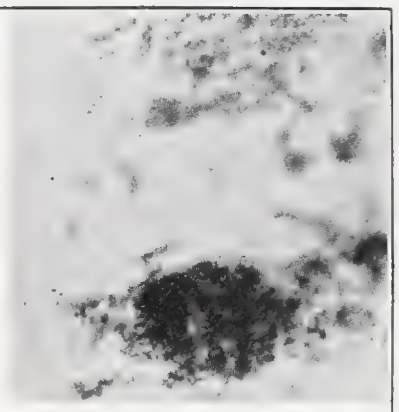

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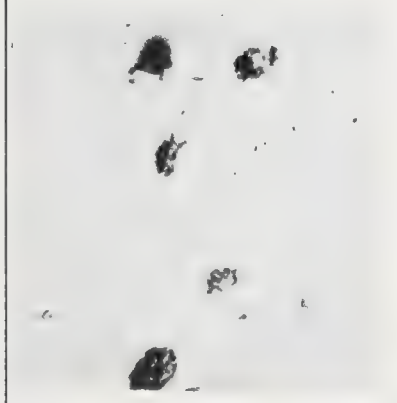

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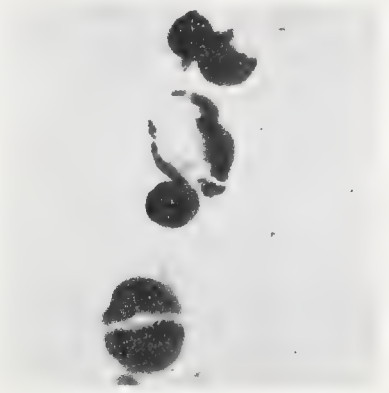

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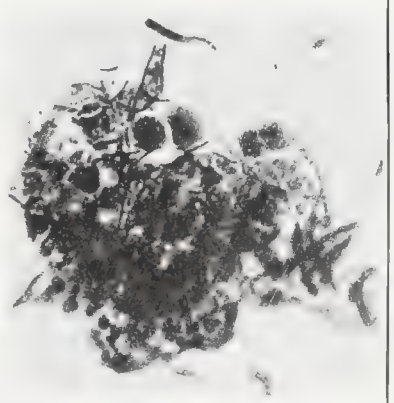

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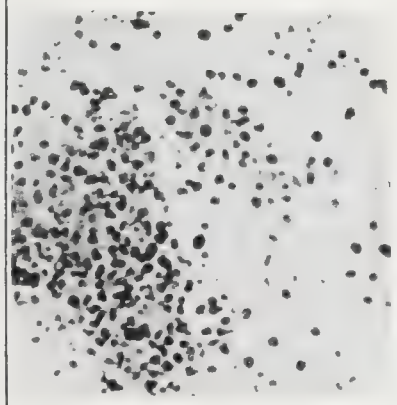

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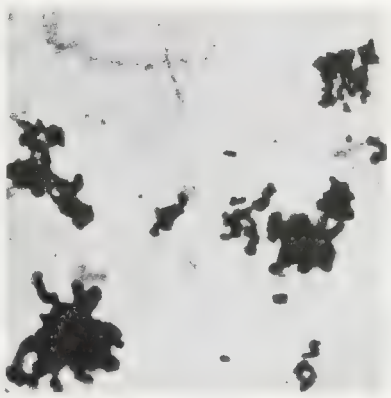

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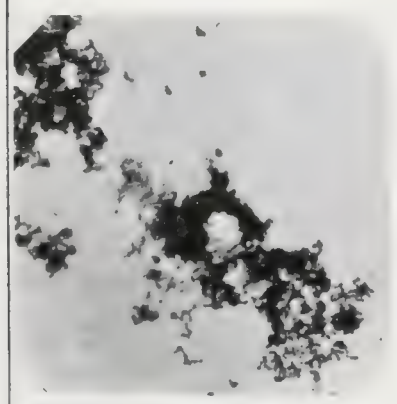

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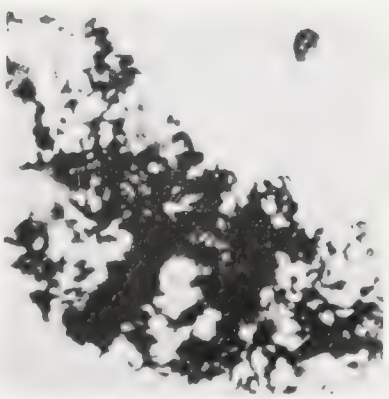

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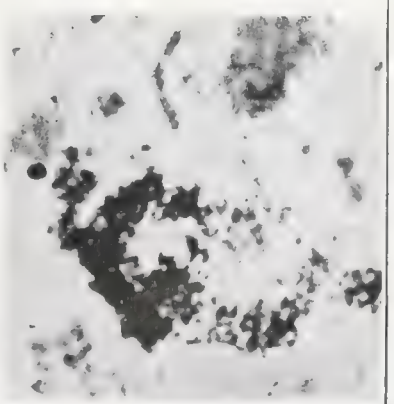

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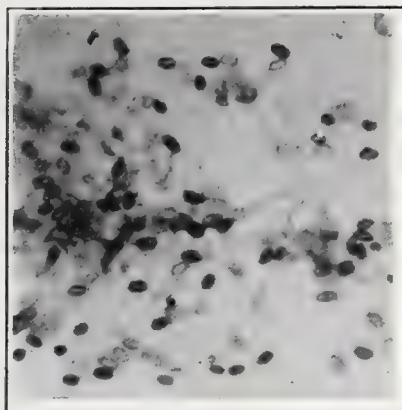
PLATE XX.

FIG. 250. (p. 178): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 44). ×1,000.
251. (p. 178): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 19). ×1,000.
252. (p. 178): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 18). ×1,000.
253. (pp. 178, 185): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 47). ×1,000.
254. (pp. 178, 185): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 14). ×1,000.
255. (pp. 178, 185): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 46). ×1,000.
256. (pp. 172, 185): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 15). ×1,000.
257. (pp. 172, 185): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 48). ×1,000.
258. (pp. 178, 185). B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 13). ×1,000.
259. (pp. 178, 185): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 49). ×1,000.
260. (pp. 178, 185): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 51). ×1,000.
261. (pp. 178, 185): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 50). ×1,000.



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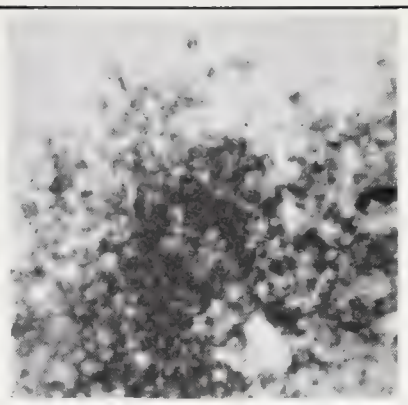

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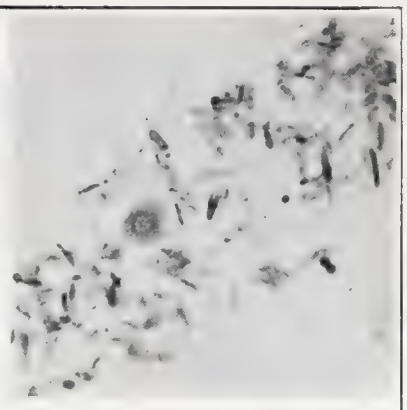

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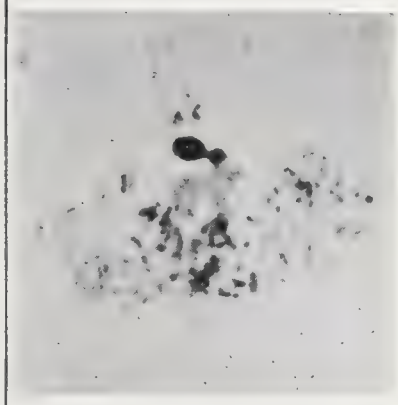

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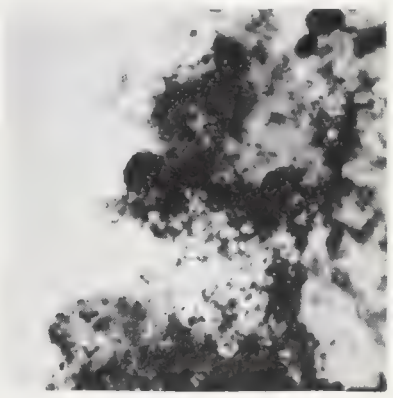

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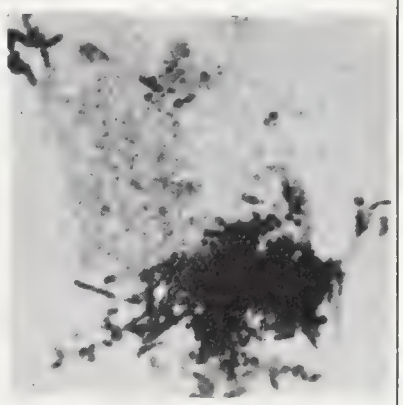

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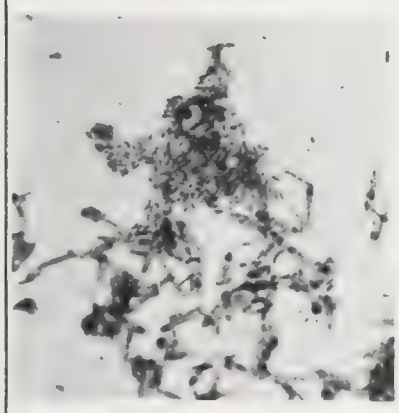

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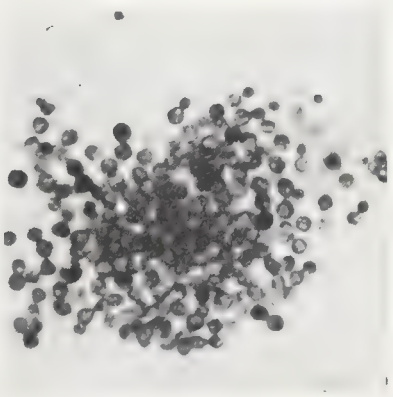

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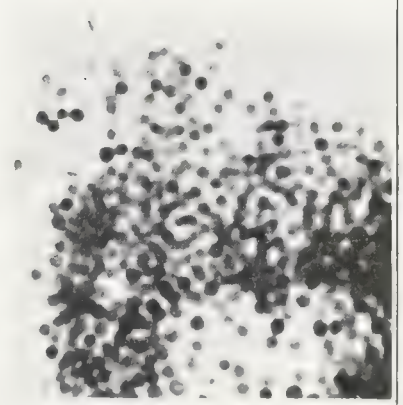

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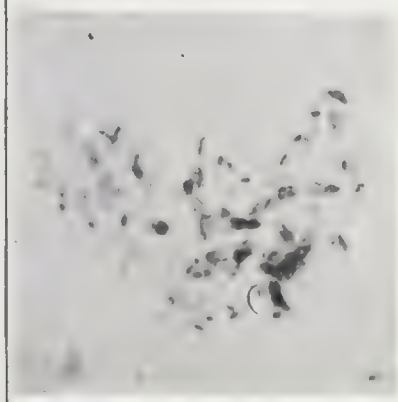

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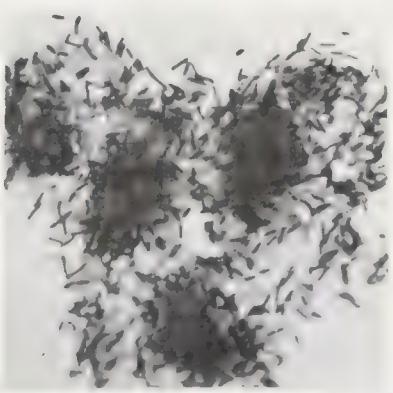

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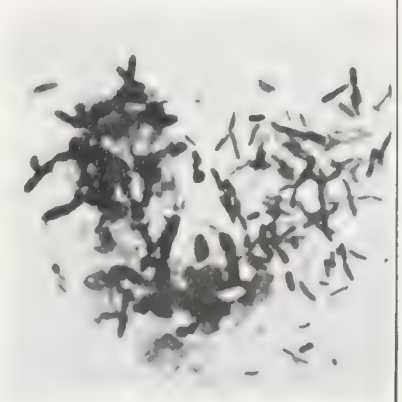

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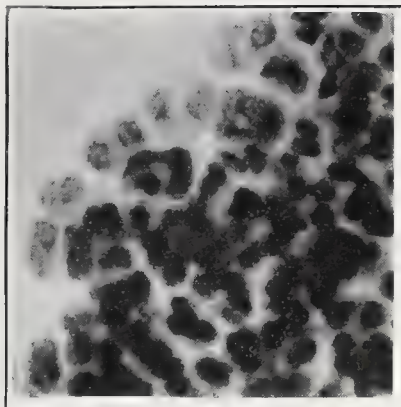
PLATE XXI.

FIG. 262. (pp. 178, 185): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 8). ×1,000.
263. (pp. 178, 185): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 63). ×1,000.
264. (pp. 178, 190): Sarcina flava. *Löhnis* and *Smith* (1916 *b*, original fig. 53). ×1,000.
265. (pp. 135, 193): Bact. acidulum. *Löhnis* and *Smith* (1916 *b*, original fig. 52). ×1,000.
266. (pp. 65, 193): B. malabarensis. *Löhnis* and *Smith* (1916 *b*, original fig. 4). ×1,000.
267. (pp. 174, 186): Yellow bacillus no. 41. *Löhnis* and *Smith* (1916 *a*, original fig. 28). ×1,000.
268. (p. 193): Nitrosomonas. *Omelianski* (1899, original fig. 2). ×1,000.
269. (p. 193): Nitrosomonas. *Winogradsky* (1892, original fig. 11). ×1,000.
270. (p. 193): Nitrosomonas. *Winogradsky* (1892, original fig. 15). ×1,000.
271. (p. 192): Clover nodule. *Hiltner* und *Störmer* (1903, original fig. II, 5). ×1,000.
272. (p. 192): Pea nodule. *Hiltner* und *Störmer* (1903, original fig. II, 6). ×1,000.
273. (p. 192): Clover nodule. *Löhnis* and *Smith* (1916 *a*, original fig. 34). ×1,000.



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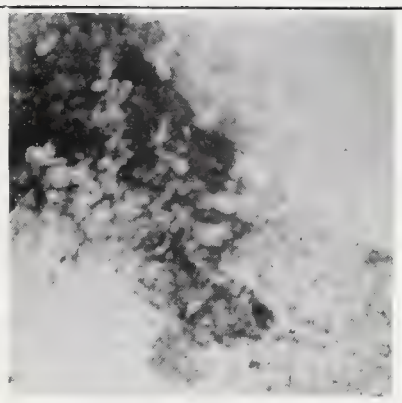

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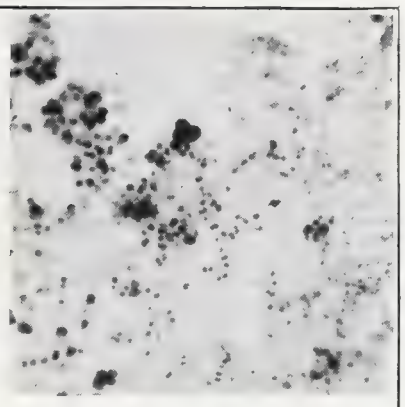

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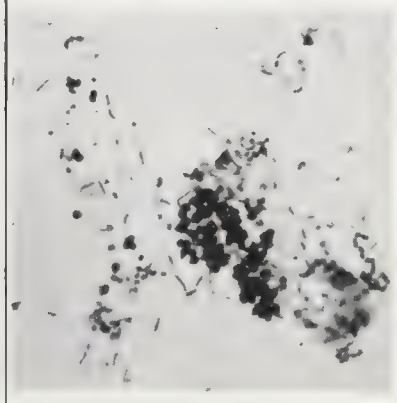

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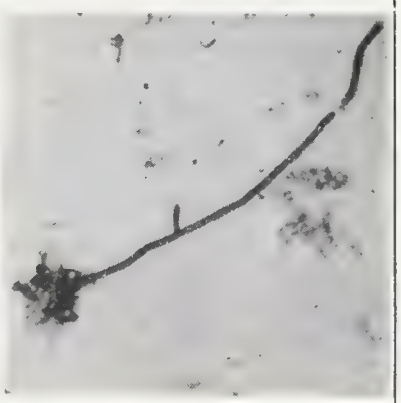
266



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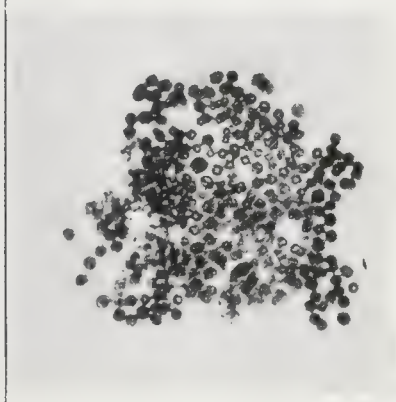

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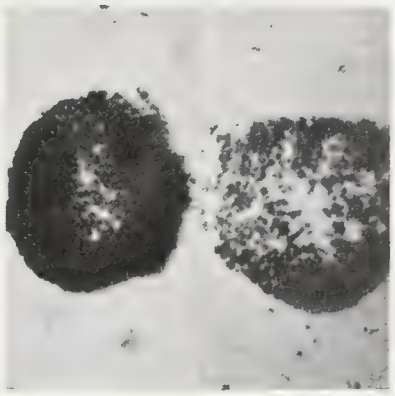

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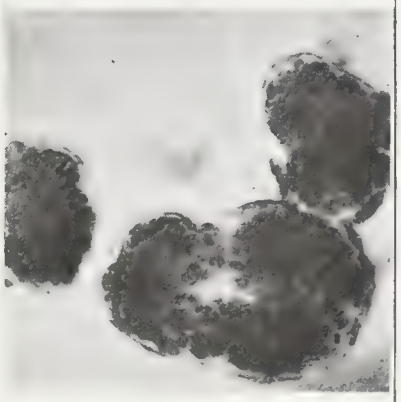

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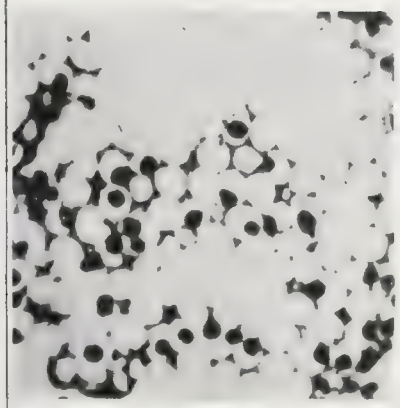

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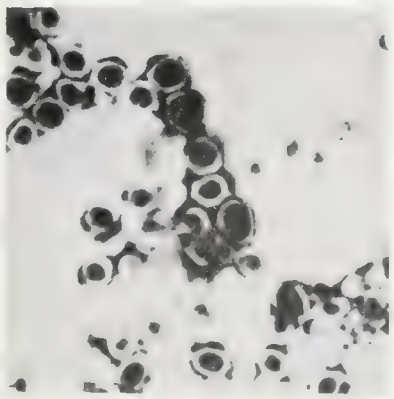

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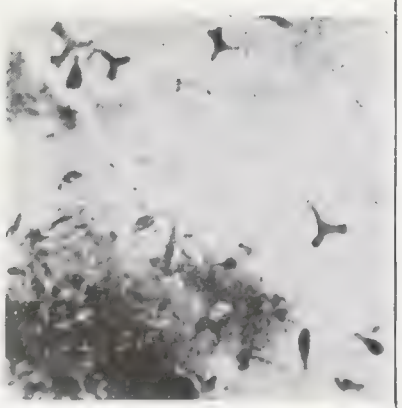

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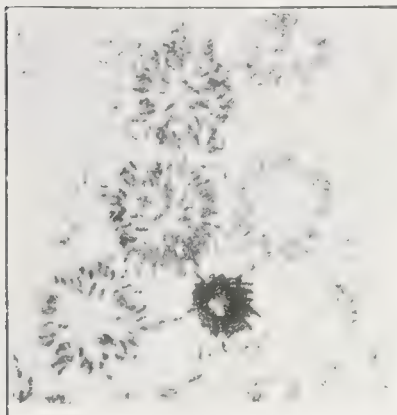
PLATE XXII.

FIG. 274. (p. 186): Rosette formation. *M. Jones* (1905, original fig. 1). ×1,500.
275. (p. 190): Ascococcus Billrothii. *F. Cohn* (1875, original fig. V, 5). ×65.
276. (p. 190): M. botryogenus. *Rabe* (1886, original fig. IV, 2). ×100.
277. (p. 200): B. radiobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 29). ×1,000.
278. (p. 197): Chromatium Okenii. *Foerster* (1892, original fig. 26). × 750.
279. (p. 197): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 1). ×1,000.
280. (p. 197): B. Azotobacter. *Löhnis* and *Smith* (1916 *a*, original fig. 2). ×1,000.
281. (p. 197): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 18). ×1,000.
282. (p. 197): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 19). ×1,000.
283. (p. 197): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 25). ×1,000.
284. (pp. 197, 204): B. Azotobacter. *Löhnis* and *Smith* (1916 *b*, original fig. 20). ×1,000.
285. (p. 197): B. fluorescens. *Löhnis* and *Smith* (1916 *b*, original fig. 23). ×1,000.



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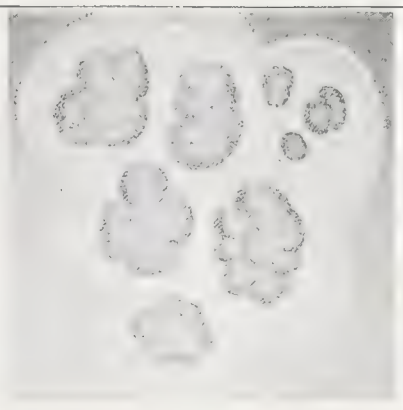

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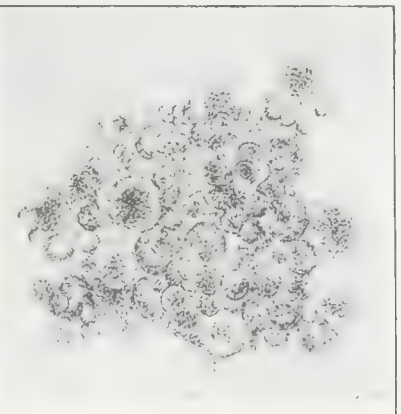

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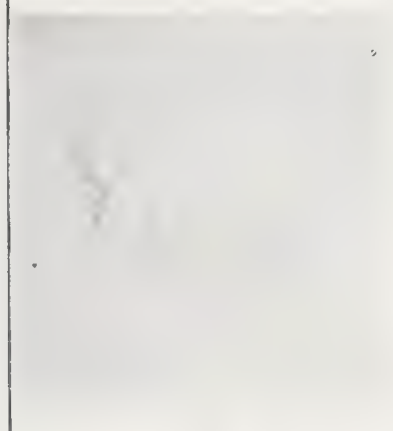

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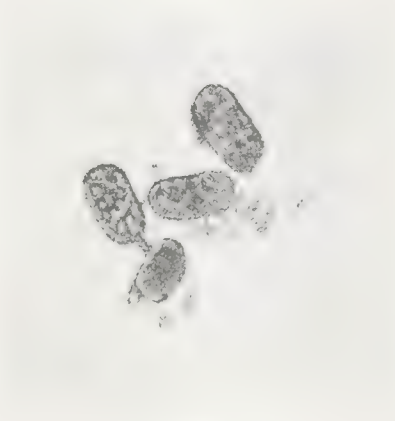

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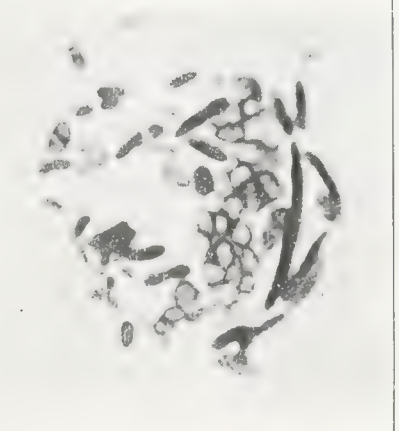

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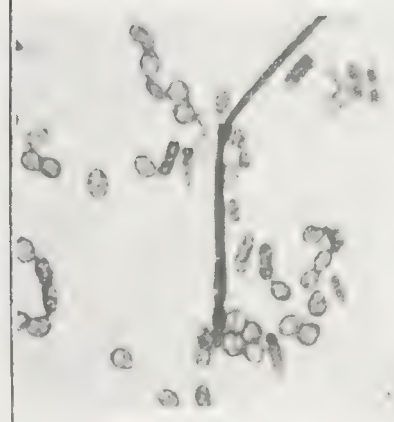

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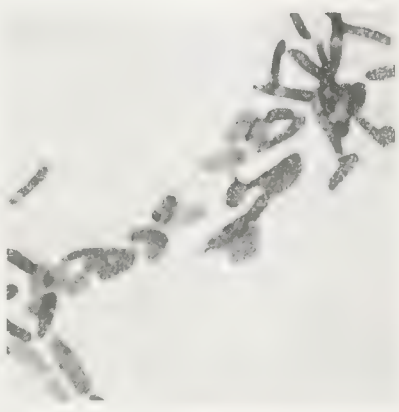

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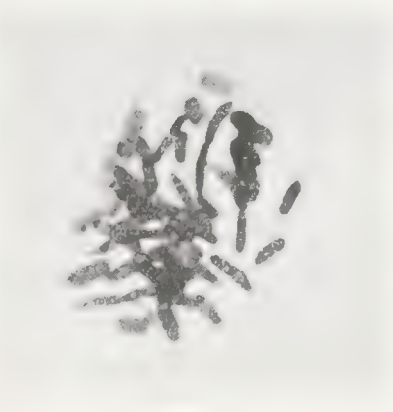

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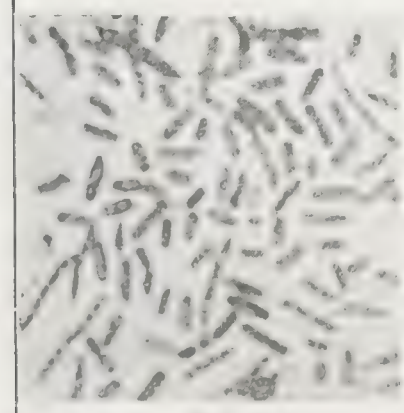

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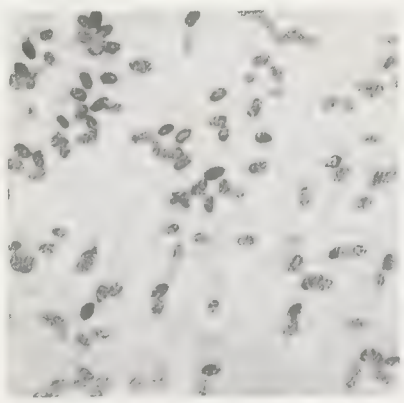

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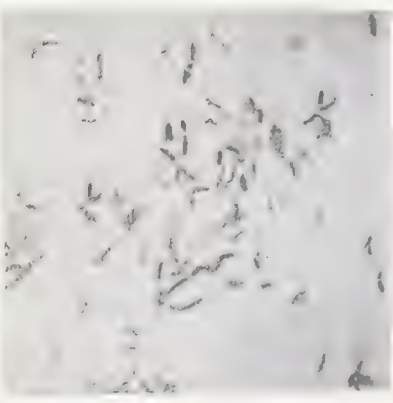

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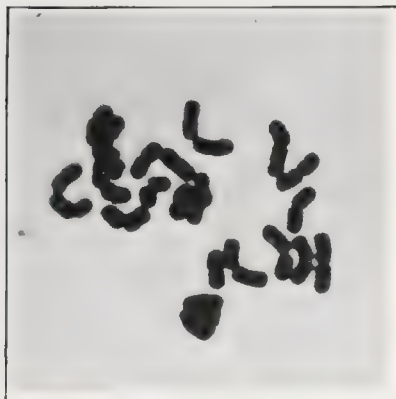
PLATE XXIII.

FIG. 286. (p. 197): B. subtilis. *Löhnis* and *Smith* (1916 *b*, original fig. 22). ×1,000.
287. (p. 197): B. subtilis. *Löhnis* and *Smith* (1916 *b*, original fig. 21). ×1,000.
288. (p. 197): B. Chauvoei. *Itzerott* und *Niemann* (1895, original fig. 48). ×1,000.
289. (p. 197): B. fluorescens. *Axelrad* (1903, original fig. 22). ×1,000.
290. (pp. 197, 201): Bact. esterificans. *Maassen* (1899, original fig. XI, 1). ×1,000.
291. (p. 197): Bacilli from straw. *Günther* (1906, original fig. 8). ×1,000.
292. (pp. 197, 202): B. subtilis. *Hiss* and *Zinsser* (1914, original fig. 125).
293. (p. 197): B. subtilis. *Hiss* and *Zinsser* (1914, original fig. 125).
294. (p. 197): Azotob. chroococcum. *Walton* (1915, original fig. II, 8). ×1,000.
295. (p. 208): Azotobacter cells not heated. *Löhnis* and *Smith* (1916 *b*, original fig. 57). ×1,000.
296. (p. 208): Azotobacter cells heated. *Löhnis* and *Smith* (1916 *b*, original fig. 58). ×1,000.
297. (p. 211): Flake from agar. *Löhnis* and *Smith* (1916 *b*, original fig. 61). ×1,000.



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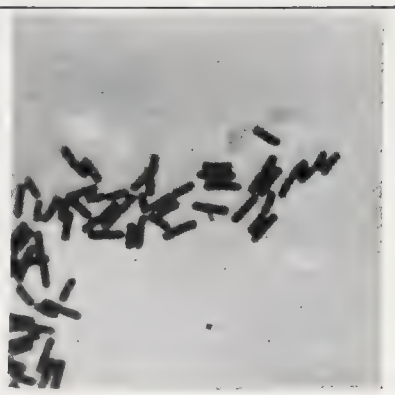

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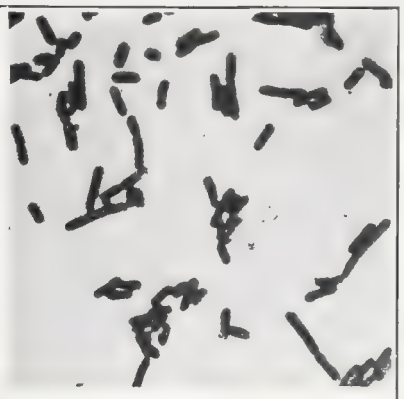

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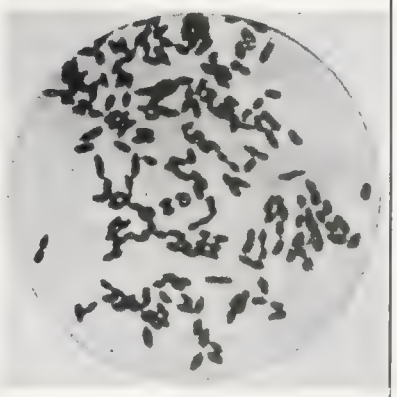

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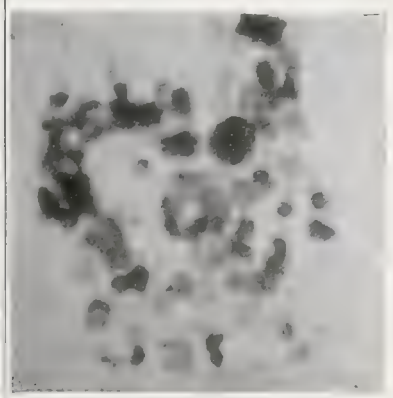

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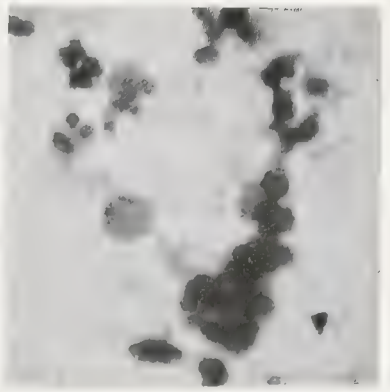

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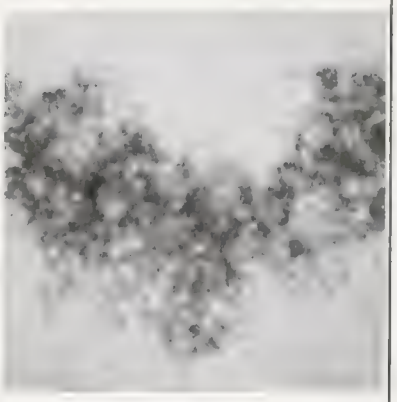

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NATIONAL ACADEMY OF SCIENCES.

Volume XVI.
THIRD MEMOIR.

THE CONSTANTS OF NATURE.

PART V.

A RECALCULATION OF THE ATOMIC WEIGHTS.

FOURTH EDITION, REVISED AND ENLARGED.

BY

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A RECALCULATION OF THE ATOMIC WEIGHTS.

(Fourth Edition, Revised and Enlarged.)

By Frank Wigglesworth Clarke.

INTRODUCTION.

In the autumn of 1877 the writer began collecting data relative to determinations of atomic weight, with the purpose of preparing a complete résumé of the entire subject, and of recalculating all the values. The work was fairly under way, the material was collected and partly discussed, when I received from the Smithsonian Institution a manuscript by Prof. George F. Becker, entitled "Atomic Weight Determinations: A Digest of the Investigations Published since 1814." This manuscript, which has since been issued [1] as Part IV of the "Constants of Nature," covered much of the ground contemplated in my own undertaking. It brought together all the evidence, presenting it clearly and thoroughly in compact form; in short, that portion of the task could not well be improved upon. Accordingly, I decided to limit my own labors to a critical recalculation of the data; to combine all the figures upon a common mathematical basis, and to omit everything which could as well be found in Prof. Becker's "Digest."

In due time my work was completed, and early in 1882 it was published.[2] About a year later Meyer and Seubert's recalculation appeared, to be followed later still by the less elaborate discussions of Sebelien and of Ostwald. All of these works differed from one another in various essential particulars, presenting the subject from different points of view, and with different methods of calculation. Each one, therefore, has its own special points of merit, and, in a sense, reinforces the others. At the same time, the scientific activity which they represent shows how widespread was the interest in the subject of atomic weights, and how fundamentally important these constants undoubtedly are.

The immediate effect of all these publications was to render manifest the imperfections of many of the data, and to point out most emphatically in what directions new work is needed to be done. This led to an extraordinary activity in the determination of atomic weights, and so much new material accumulated that in 1897 [3] a second edition of the work, revised to date, became necessary. A third edition,[4] much enlarged, appeared in 1910, and since then a large amount of new work has been done, with great improvements in technique, especially by Richards and his colleagues at Harvard University, by Edgar F. Smith in Philadelphia, and by Guye at Geneva, not to mention many other workers of high merit. The assimilation of this new material, and its combination with the older data, is the object of the present volume.

At the very beginning of my work, a fundamental question confronted me. Should I treat the investigations of different individuals separately, or should I combine similar data together in a manner irrespective of persons? For example, ought I, in estimating the atomic weight of silver, to take Stas's work by itself, Marignac's work by itself, and so on, and then average the results together; or should I rather combine all series of figures relating to the composition of potassium chlorate into one mean value, and all the data concerning the composition of silver chloride into another mean, and, finally, compute from such general means the constant sought to be established? The latter plan was finally adopted; in fact, it was

[1] Smithsonian Miscellaneous Collections, vol. 27, serial No. 358, pp. 152.
[2] Smithsonian Miscellaneous Collections, vol. 27, serial No. 441, pp. 279.
[3] Smithsonian Miscellaneous Collections, vol. 38, serial No. 1075, pp. vi, 370.
[4] Ibid., vol. 54, No. 3, pp. iv, 548.

rendered necessary by the method of least squares, which, in a special, limited form, was chosen as the best method of dealing with the problem.

The mode of discussion and combination of results was briefly as follows. The formulæ employed are given in another place. Beginning with the ratio between oxygen and hydrogen, each series of experiments was taken by itself, its arithmetical mean was determined, and the probable error of that mean was computed. Then the several means were combined according to the appropriate formula, each one receiving a weight dependent upon its probable error. The general mean thus established was taken as the most probable value for the ratio, and at the same time its probable error was mathematically assigned. In the first two editions of this work it was used to give the atomic weight of oxygen referred to hydrogen as unity. In the third edition the oxygen standard was adopted, and the atomic weight of hydrogen is referred to it. This is an accordance with the decisions of the International Committee on Atomic Weights; although my personal preference, on theoretical grounds, is for the hydrogen standard. The subsequent computations, however, are rendered simpler by assuming that O = 16, and that is another reason for my change of policy.

Next in order came a number of elements which were best considered together; namely, silver, chlorine, bromine, iodine, potassium, sodium, nitrogen, sulphur, and carbon. Their atomic weights, with those of hydrogen and oxygen, form a fundamental group, by means of which other atomic weights are determined. Direct comparisons with oxygen or hydrogen are relatively few; indirect determinations with the aid of silver and the halogens are many. For the elements in question there were data from many experimenters. All similar figures, that is, the figures for each ratio, were first reduced to a common standard, and then the individual means were combined into general means. Thus all the data were condensed into seventy-one ratios, from which a number of values for each atomic weight could be computed. The ratios represent the actual experimental work; the atomic weights are inferential. Finally, the several values for each atomic weight are treated as if they were means of the usual type, and combined by the method of least squares into a general mean, which is suppoesd to represent the most probable value for each constant. The fundamental values having been determined, they are next applied to the calculation of what may be called the secondary atomic weights, and in this work the probable error of each term in each ratio is taken into account. This will appear more clearly evident in the subsequent actual calculations.

But although the discussion of atomic weights is ostensibly mathematical, it cannot be purely so. Chemical considerations are necessarily involved at every turn. In assigning weights to mean values I have been, for the most part, rigidly guided by mathematical rules; but in some cases I have been compelled to reject series of data which were mathematically excellent but chemically worthless because of constant errors. In certain instances there were grave doubts as to whether particular figures should be included or rejected in the calculation of means, there having been legitimate reasons for either procedure. Probably many chemists would differ with me upon such points of judgment. In fact, it is doubtful whether any two chemists, working independently, would handle all the data in precisely the same way, or combine them so as to produce the same final results. Neither would any two mathematicians follow identical rules or reach identical conclusions. In calculating the atomic weight of any element those values are assigned to other elements which have been determined in previous chapters. Hence a variation in the order of discussion might lead to slight differences in the final results.

As a matter of course the data herein combined are of very unequal value. In many series of experiments the weighings have been reduced to a vacuum standard; but in other cases this correction has been neglected. In a majority of instances the errors thus introduced are slight; nevertheless they exist, and interfere more or less with all attempts at a theoretical consideration of the results.[1]

[1] For a discussion of these vacuum corrections see Guye and Zachariades, C. R. Acad. Sci., 149, 593. The errors in reductions to a vacuum are larger than has been commonly supposed. For a reply by Richards and Baxter see Journ. Amer. Chem. Soc., 32, 507. Also Guye and Renard, Journ. Chim. Phys., 14, 55, and Guye, pp. 25, and 83. In the same volume, pp. 195, 204, Guye and Germann discuss other sources of error in atomic weight determinations. See also Van Laar (Ibid., 17, 266, 1919) on the calculation of atomic weights.

Necessarily, this work omits many details relative to experimental methods, and particulars as to the arrangement of special forms of apparatus. For such details original memoirs must be consulted. Their inclusion here would have rendered the work unwarrantably bulky. There is such a thing as overexhaustiveness of treatment, which is equally objectionable with underthoroughness.

Of course, none of the results reached in this revision can be considered as final. Every one of them is liable to future corrections. To my mind the real value of the work, great or little, lies in another direction. The data have been brought together and reduced to common standards, and for each series of figures the probable error has been determined. Thus far, however much my methods of combination may be criticized, I feel that my labors will have been useful. The ground is cleared, in a measure, for future experimenters; it is possible to see more distinctly what remains to be done; some clues are furnished as to the relative merits of different series of results.

On the mathematical side my method of recalculation has obvious deficiencies. It is special rather than general, and at some future time, when a sufficiently large mass of evidence has accumulated, it must give way to a more thorough mode of treatment. For example, the ratio $Ag_2 : BaBr_2$ has been used for computing the atomic weight of barium, the atomic weights of silver and bromine being supposed to be known. But these atomic weights are subject to small errors, and they are superimposed upon that of the ratio itself in the process of calculation. Obviously, the ratio should contribute to our knowledge of all three of the atomic weights involved in it, its error being distributed into three parts instead of appearing in one only. The errors may be in part compensatory; but that is not certainly known.

Suppose now that for every element we had a goodly number of atomic weight ratios, connecting it with at least a dozen other elements, and all measured with reasonable accuracy. These hundreds of ratios could then be treated as equations of observation, reduced to linear form, and combined by the general method of least squares into normal equations. All errors would thus be distributed, never becoming cumulative; and the normal equations, solved once for all, would give the atomic weights of all the elements simultaneously. The process would be laborious, but the result should be the closest possible approach to accuracy. The data as yet are inadequate, although some small groups of ratios may be handled in that way; but in time the method is sure to be applied, and indeed to be the only general method applicable. Even if every ratio was subject to some small constant error, this, balanced against the similar errors of other ratios, would become accidental or unsystematic with reference to the entire mass of material, and would practically vanish from the final means.

Concerning this subject of constant and accidental errors, a word may be said here. My own method of discussion eliminates the latter, which are, in great part at least, removable by ordinary averaging; but the constant errors, vicious and untractable, remain, at least partially. Still, where many ratios are considered, even the systematic errors may in part compensate each other, and do less harm than might be expected. They have, moreover, a peculiarity which deserves some attention.

In the discussion of instrumental observations, the systematic errors are commonly constant, both as to direction and as to magnitude. They are therefore independent of the accidental errors, and computation of means leaves them untouched. But in the measurement of chemical ratios the constant errors are most frequently due to an impurity in one of the materials investigated. If different samples of a substance are studied, although all may contain the same impurity, they are not likely to contain it in the same amount; and so the values found for the ratio will vary. In other words, such errors may be constant in direction, but variable in magnitude. That variation appears in the probable error computed for the series of observations, diminishes its weight when combined with other series, and so, in part, corrects itself. It is not removed from the result, but it is self-mitigated. The constant errors familiar to the physicist and astronomer are obviously of a different order.

That all methods of averaging are open to objections, I am, of course, perfectly aware. I also know the doubts which attach to all questions of probable error, and to all combinations

of data which depend upon them. I have, however, preferred to face these objections and to recognize these doubts rather than to adopt any arbitrary scheme which permits of a loose selection of data. After all, the use of probable error as a means of weighting is only a means of weighting, and perhaps more justifiable than any other method of attaining the same result. When observations are weighted empirically—that is, by individual judgment—far greater dangers arise. Almost unconsciously, the work of a famous man is given greater weight than that of some obscure chemist, although the latter may ultimately prove to be the best. But the probable error of a series of measurements is not affected by the glamor of great names; and the weight which it assigns to the observations is at least as good as any other. In the long run, I believe it assigns weight more accurately, and therefore I have trusted to its indications, not as if it were a mathematical fetish, but regarding it as a fairly safe guide, even though it is not infallible.

One possibly weak point in the method adopted deserves to be mentioned. Its fairness depends in part upon the fairness of the experimenter. One chemist, making a series of measurements, gives all of his determinations. Another chemist selects those which are most concordant, and suppresses others which seem to him less trustworthy. The latter series, therefore, is likely to receive higher weight than belongs to it; while the former series will be underweighted. The rejection of data, even by the man who is most familiar with them, is always a dangerous proceeding, and one which should be discouraged.

The other and more usual method of adjusting the atomic weights, that of selecting determinations in accordance with their apparent chemical merit, has recently been followed by Brauner. In his excellent and critical discussion of the subject, now appearing in Abegg's Handbuch der anorganischen Chemie, he gives all the determinations for each element, and then assigns preference to those which most appeal to his judgment. In most instances his findings agree with mine, and therefore our conclusions reinforce each other. Sometimes we differ, and in such cases it would seem that new determinations are desirable. When values derived from different sources, and computed by different methods are concordant, they may be regarded as probably well established; but even then certainty is not attained. The history of atomic weight determinations bears abundant witness to this assertion.

For example: Until within very recent years the work of Stas, emphasized by that of Marignac, was regarded as almost final. Now, however, some of the ratios measured by these chemists are found to be out of harmony with the best modern investigations, and there is a tendency toward rejecting the older work altogether. But the researches of Stas give a homogeneous and concordant group of atomic weights, which cannot be entirely thrown aside without much more evidence against them than as yet exists. It is probable that the silver used by Stas contained occluded oxygen, as was pointed out by Dumas;[1] and this would account for some, but not all of the variations from recent revisions of the ratios. It is also probable, as Richards has shown, that Stas underrated the solubility of silver chloride. How large these errors may be in Stas's work, assuming them to exist, is uncertain; and to assign zero weight to his determinations would be too extreme a procedure. His data and Marignac's are therefore retained in the present recalculation, with the proper mathematical weight; and the final results seem to be satisfactory. Indeed, the Stas values for silver, chlorine, and bromine, applied to the determinations of other atomic weights, sometimes give more concordant results than the modern figures. This is especially true in the cases of cæsium, barium, and magnesium, although the discrepancies are not large. The data of Richards and his collaborators for the chlorides of these metals give a ratio between silver and chlorine in agreement with the measurements by Stas, and lower than that which Richards and Wells have established. If, therefore, the work of Stas is in error, the same error inheres in the atomic weights of the three metals above mentioned, and the latter, even if the uncertainty is small, ought to be revised. The sharp concordance found when the atomic weights were computed with Stas's figures is either illusive, or else the modern data for silver and chlorine are wrong. The first of these alternatives is the more

[1] Ann. Chim. Phys. (5), 14, 289. See also the Appendix to the first edition of this Recalculation, in which the influence of a correction for occluded oxygen is considered.

probable. In spite of the discordance now evident, the determinations for cæsium, barium, and magnesium are by far the best we have, and their uncertainties need not be regarded as serious.

In Meyer and Seubert's recalculation, weights are assigned in quite a novel manner. In each series of experiments the maximum and minimum results are given, but instead of the mean there is a value deduced from the sum of the weighings—that is, each experiment is weighted proportionally to the mass of the material handled in it. For this method I am unable to find any complete justification. Of course, the errors due to the operations of weighing become proportionally smaller as the quantity of material increases, but these errors, with modern apparatus, are relatively unimportant. The real errors in atomic weight determinations are much larger than these, and due to different causes. Hence an experiment upon ten grammes of material may be a little better than one made upon five grammes, but it is by no means necessarily twice as good. The ordinary mean of a series of observations, with its measure of concordance, the probable error, is a better value than one obtained in the manner just described. If only errors of weighing were to be considered, Meyer and Seubert's summation method would be valid, but in the presence of other and greater errors it seems to have but little real pertinency to the problem at hand.

Although all reasonable efforts have been made to ensure the completeness of this work, it is possible that some recent determinations of atomic weights have been missed. Because of the war in Europe there has been great irregularity in the receipt of foreign journals, and many numbers of German and Austrian publications have not yet come to hand. It is possible that some of the missing journals may contain data which should be utilized here.

In addition to the usual periodicals, the following works have been freely used by me in the preparation of this volume:

Berzelius, J. J. Lehrbuch der Chemie. 5 Auflage. Dritter Band. SS. 1147–1231. 1845.

Van Geuns, W. A. J. Prœve eener Geschiedenis van de Æquivalentgetallen der Scheikundige Grondstoffen en van hare Soortelijke Gewigten in Gasvorm, voornamelijk in Betrekking tot de vier Grondstoffen de Bewerktuigde Natuur. Amsterdam, 1853.

Mulder, E. Historisch-Kritisch Overzigt van de Bepalingen der Æquivalent-Gewigten van 13 Eenvoudige Ligchamen. Utrecht, 1853.

Mulder, L. Historisch-Kritisch Overzigt van de Bepalingen der Æquivalent-Gewigten van 24 Metalen. Utrecht 1853.

Oudemans, A. C., Jr. Historisch-Kritisch Overzigt van de Bepaling der Æquivalent-Gewigten van Twee en Twintig Metalen. Leiden, 1853.

Becker, G. F. Atomic Weight Determinations: a Digest of the Investigations Published since 1814. Smithsonian Miscellaneous Collections, Vol. 27, No. 358. Washington, 1880.

Stas, J. S. Untersuchungen über die Gesetze der Chemischen Proportionen über die Atomgewichte und ihre gegenseitigen Verhältnisse. Uebersetzt von Dr. L. Aronstein. Leipzig, 1867.
See also his "Oeuvres Complètes," 3 vols., published at Bruxelles in 1894.[1]

Meyer, L., and Seubert, K. Die Atomgewichte der Elemente, aus den Originalzahlen neu berechnet. Leipzig, 1883.

Sebelien, J. Beitrage zür Geschichte der Atomgewichte. Braunschweig, 1884.

Ostwald, W. Lehrbuch der allgemeinen Chemie. Zweite Aufl. I Band. SS. 18–138. Leipzig, 1891.

Marignac, J. C. G. De. Oeuvres Complètes. 2 vols. Geneva, 1902.

Richards, T. W. Experimentelle Untersuchungen ueber Atomgewichte. Hamburg and Leipzig, 1909.

Abegg's Handbuch, containing Brauner's recalculation, has already been mentioned. Its value is very great. The four Dutch monographs above cited are also especially valuable. They represent a revision of all atomic weight data down to 1853, as divided between four writers.

FORMULÆ FOR THE CALCULATION OF PROBABLE ERROR.

The formula for the probable error of an arithmetical mean, familiar to all physicists, is as follows:

(1.) $$e = 0.6745\sqrt{\frac{S}{n(n-1)}}$$

[1] The citations used in the present Recalculation are all from the Oeuvres Complètes.

Here n represents the number of observations or experiments in the series, and S the sum of the squares of the variations of the individual results from the mean.

In combining several arithmetical means, representing several series, into one general mean, each receives a weight inversely proportional to the square of its probable error. Let A, B, C, etc., be such means, and a, b, c their probable errors respectively. Then the general mean is determined by the formula:

$$(2.) \qquad M = \frac{\frac{A}{a^2}+\frac{B}{b^2}+\frac{C}{c^2}\cdots\cdots}{\frac{1}{a^2}+\frac{1}{b^2}+\frac{1}{c^2}\cdots\cdots}$$

For the probable error of this general mean we have:

$$(3.) \qquad e = \frac{1}{\sqrt{\frac{1}{a^2}+\frac{1}{b^2}+\frac{1}{c^2}\cdots\cdots}}$$

In the calculation of atomic and molecular weights the following formulæ are used: Taking, as before, capital letters to represent known quantities, and small letters for their probable errors, respectively, we have for the probable error of the sum or difference of two quantities, A and B:

$$(4.) \qquad e = \sqrt{a^2+b^2}$$

For the product of A multiplied by B the probable error is

$$(5.) \qquad e = \sqrt{(Ab)^2+(Ba)^2}$$

For the product of three quantities, ABC:

$$(6.) \qquad e = \sqrt{(BCa)^2+(ACb)^2+(ABc)^2}$$

For a quotient, $\frac{B}{A}$, the probable error becomes

$$(7.) \qquad e = \frac{\sqrt{\left(\frac{Ba}{A}\right)^2+b^2}}{A}$$

Given a proportion, A:B::C:x, the probable error of the fourth term is as follows:

$$(8.) \qquad e = \frac{\sqrt{\left(\frac{BCa}{A}\right)^2+(Cb)^2+(Bc)^2}}{A}$$

This formula is used in nearly every atomic weight calculation, and is, therefore, exceptionally important. Barely a more complicated case arises in a proportion of this kind:

$$A:B::C+x:D+x$$

In this proportion the unknown quantity occurs in two terms. Its probable error is found by this expression, and is commonly large:

$$(9.) \qquad e = \sqrt{\frac{(C-D)^2}{(A-B)^4}(B^2a^2+A^2b^2)+\frac{B^2c^2+A^2d^2}{(A-B)^2}}$$

When several independent values have been calculated for an atomic weight they are treated like means, and combined according to formulæ (2) and (3). Each final result is, therefore, to be regarded as the general or weighted mean of all trustworthy determinations. This method of combination is not theoretically perfect, but it seems to be the one most available for present purposes.

THE FUNDAMENTAL RATIOS.

In the determination of atomic weights, a small number of values are to be regarded as fundamental. They are the standards of reference; and by comparison with them all the other atomic weights are established. Two of these values, the atomic weights of hydrogen and

oxygen, are primary; that is, one or the other of them is the basis of the entire system; hydrogen as unity in the older arrangements; oxygen equal to 16 in the more modern scheme. Over the relative merits of these two ultimate standards there has been much controversy; but with discussions of that sort the present work has nothing to do. The oxygen standard is now recognized by international agreement, and will therefore be accepted here.

Comparatively few of the atomic weights, however, are fixed by direct comparison with either oxygen or hydrogen. In most cases other values intervene, and especially the atomic weights of silver, chlorine, bromine, iodine, nitrogen, carbon, sulphur, potassium and sodium. These constants are first to be determined, and their establishment may be compared to a primary triangulation, of which the hydrogen-oxygen ratio is the base line. The lithium ratios may also be included here, for the reason that they give one of the best determinations of the atomic weight of silver. The ratios connecting these 12 elements with one another are to be discussed in the following pages.

THE OXYGEN-HYDROGEN RATIO.

Leaving out the account of the earliest researches, which now have only historical interest, the first determinations of this ratio worth considering are those by Dulong and Berzelius,[1] who, like some of their successors, effected the synthesis of water over heated oxide of copper. The essential features of the method are in all cases the same. Hydrogen is passed over the hot oxide, and the water thus formed is collected and weighed. From this weight and the loss of weight which the oxide undergoes, the composition of water is readily calculated. Dulong and Berzelius made but three experiments, which gave the following percentages of oxygen and hydrogen in water:

O.	*H.*
88.942	11.058
88.809	11.191
88.954	11.046

From these figures the ratio H : O becomes—

16.124
15.863
16.106

Mean, 16.031, ± .057

As the weighings were not reduced to a vacuum, this correction was afterwards applied by Clark,[2] who showed that these syntheses really make O = 15.894; or, in Berzelian terms, if O = 100, H = 12.583. The value 15.894, ± .057 we may therefore take as the true result of Dulong and Berzelius' experiments, a figure curiously near that reached in the latest researches.

In 1842 Dumas[3] published his elaborate investigation upon the composition of water. The first point was to get pure hydrogen. This gas, evolved from zinc and sulphuric acid, might contain oxides of nitrogen, sulphur dioxide, hydrosulphuric acid, and arsenic hydride. These impurities were removed in a series of wash bottles; the H_2S by a solution of lead nitrate, the H_3As by silver sulphate, and the others by caustic potash. Finally, the gas was dried by passing through sulphuric acid, or, in some of the experiments, over phosphorus pentoxide. The copper oxide was thoroughly dried, and the bulb containing it was weighed. By a current of dry hydrogen all the air was expelled from the apparatus. and then, for 10 or 12 hours, the oxide of copper was heated to dull redness in a constant stream of the gas. The reduced copper was allowed to cool in an atmosphere of hydrogen. The weighings were made with the bulbs exhausted of air. The following table gives the results:

Column A contains the symbol of the drying substance; B gives the weight of the bulb and copper oxide; C, the weight of bulb and reduced copper; D, the weight of the vessel used for collecting the water; E, the same, plus the water; F, the weight of oxygen; G, the weight of water formed; H, the crude equivalent of H when O = 10,000; I, the equivalent of H, corrected

[1] Thomson's Annals of Philosophy, July, 1821, p. 50. [2] Phil. Mag. (3), 20, 341. [3] C. R. Acad. Sci., 14, 537.

for the air contained in the sulphuric acid employed. This correction is not explained, and seems to be questionable.

A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*H.*	*I.*
H_2SO_4	291.985	278.806	480.807	495.634	13.179	14.827	1250.5	1249.6
H_2SO_4	344.548	324.186	488.227	511.132	20.362	22.905	1249.0	1248.0
H_2SO_4	316.671	296.175	439.711	462.764	20.495	23.053	1248.1	1247.2
P_2O_5	625.829	568.825	884.190	948.323	57.004	64.044	1250.6	1249.0
H_2SO_4	804.546	728.182	887.331	973.291	76.364	85.960	1256.2	1254.6
H_2SO_4	533.726	490.155	867.159	916.206	43.571	49.047	1256.3	1255.0
H_2SO_4	661.915	627.104	839.304	878.482	34.811	39.178	1254.6	1253.3
P_2O_5	612.625	566.738	824.624	876.244	45.887	51.623	1250.0	1249.0
P_2O_5	904.643	844.612	822.660	890.246	60.031	67.586	1258.3	1255.1
H_2SO_4	642.325	590.487	741.095	799.417	51.838	58.320	1250.4	1248.9
P_2O_5	587.645	535.137	874.832	933.910	52.508	59.078	1251.2	1249.0
P_2O_5	673.280	613.492	931.487	998.700	59.789	67.282	1253.3	1250.8
H_2SO_4	660.855	598.765	682.374	752.273	62.090	69.899	1257.7	1254.8
H_2SO_4	642.325	590.847	741.097	799.455	51.838	58.360	1258.1	1256.2
H_2SO_4	937.845	881.362	1064.762	1128.319	56.483	63.577	1255.8	1252.2
P_2O_5	756.352	719.563	878.640	920.030	36.789	41.390	1250.6	1249.1
P_2O_5	754.162	720.000	887.817	926.275	34.162	38.458	1257.3	1255.1
P_2O_5	759.762	727.632	888.662	924.837	32.133	36.175	1257.5	1254.7
P_2O_5	747.652	716.825	877.862	912.539	30.827	34.677	1248.8	1248.0
						Means	1253.3	1251.5

In the sum total of these 19 experiments, 840.161 grammes of oxygen form 945.439 grammes of water. This gives, in percentages, for the composition of water—oxygen, 88.864; hydrogen, 11.136. Hence the ratio H : O, calculated in mass, is 1 : 15.9608. In the following the values are deduced from the individual data given under the headings F and G:

15.994	15.984
16.014	15.958
16.024	15.902
15.992	15.987
15.916	15.926
15.916	15.992
15.943	15.904
16.000	15.900
15.892	16.015
15.995	

Mean, 15.9607. ± .0070

In calculating the above several discrepancies were noted, probably due to misprints in the original memoir. On comparing columns B and C with F, or D and E with G, these anomalies chiefly appear. They were detected and carefully considered in the course of my own calculations; and, I believe, eliminated from the final result.

The investigation by Erdmann and Marchand [1] followed closely after that of Dumas. The method of procedure was essentially that of the latter chemist, differing from it only in points of detail. The hydrogen used was prepared from zinc and sulphuric acid, and the zinc, which contained traces of carbon, was proved to be free from arsenic and sulphur. The copper oxide was made partly from copper turnings and partly by the ignition of the nitrate. The results obtained are given in two series, in one of which the weighings were not actually made in vacuo, but were, nevertheless, reduced to a vacuum. In the second series the copper oxide and copper were weighed in vacuo. The following table contains the corrected weights of water obtained and of the oxygen in it, with the value found for the ratio in a third column. The weights are given in grammes.

[1] Journ. prakt. Chem., 26, 461. 1842.

First series.

Wt. Water.	*Wt. O.*	*Ratio.*
62.980	55.950	15.917
95.612	84.924	15.891
94.523	84.007	15.977
35.401	31.461	15.970
		Mean, 15.939±.014

Second series.

Wt. Water.	*Wt. O.*	*Ratio.*
41.664	37.034	15.996
44.089	39.195	16.018
53.232	47.321	16.011
55.636	49.460	16.017
		Mean, 16.010±.0036

The effect of discussing these two series separately is somewhat startling. It gives to the four experiments in Erdmann and Marchand's second group a weight vastly greater than their other four and Dumas's nineteen taken together. For so great a superiority as this there is no adequate reason; and it is highly probable that it is due almost entirely to fortunate coincidences rather than to greater accuracy of work. We will, therefore, treat Erdmann and Marchand's experiments as one series, giving all equal weight, the mean now becoming O=15.975±.0113. If we take the sum of the eight experiments, 483.137 grammes water and 429.352 grammes oxygen, and compute from these figures, then O=15.966.

It would be easy to point out the sources of error in the foregoing sets of determinations, but it is hardly worth while to do so in detail. A few leading suggestions are enough for present purposes. First, there is an insignificant error due to the occlusion of hydrogen by metallic copper, rendering the apparent weight of the latter a trifle too high. Secondly, as shown by Dittmar and Henderson, hydrogen dried by passage through sulphuric acid becomes perceptibly contaminated with sulphur dioxide. In the third place, Morley[1] has found that hydrogen prepared from zinc always contains carbon compounds not removable by absorption and washing. Erdmann and Marchand themselves note that their zinc contained traces of carbon. Finally, copper oxide, especially when prepared by the ignition of the nitrate, is very apt to contain gaseous impurities, and particularly occluded nitrogen.[2] Any or all of these sources of error may have vitiated the three investigations so far considered, but it would be useless to speculate as to the extent of their influence. They amply account, however, for the differences between the older and the later determinations of the constant under discussion.

Leaving now out of account all measurements of the relative densities of hydrogen and oxygen, to be considered separately later, the next determination to be noted is that published by J. Thomsen in 1870.[3] Unfortunately this chemist has not published the details of his work, but only the end results. Partly by the oxidation of hydrogen over heated copper oxide, and partly by its direct union with oxygen, Thomsen finds that at the latitude of Copenhagen, and at sea level, one liter of dry hydrogen at 0° and 760 mm. pressure will form .8041 gramme of water. According to Regnault, at this latitude, level, temperature, and pressure, a liter of hydrogen weighs .08954 gramme. From these data, O=15.9605. It will be seen at once that Thomsen's work depends in great part upon that of Regnault and is therefore subject to the corrections recently applied by Crafts and others to the latter. These corrections, which will be discussed further on, reduce the value of O from 15.9605 to 15.91. In order to combine this value with others it is necessary to assign it weight arbitrarily, and as Thomsen made eight experiments, which are said to be concordant, it may be fair to rank his determination with that of Erdmann and Marchand and to assume for it the same probable error. The value 15.91±.0113 will therefore be taken as the outcome of Thomsen's research.

[1] Amer. Chem. Journ., 12, 469. 1890. [2] See Richards's work cited in the chapter on copper. [3] Ber. Deutsch. chem. Ges., 3, 928. 1870.

In 1887 Cooke and Richards published the results of their elaborate investigation.[1] These chemists weighed hydrogen, burned it over copper oxide, and weighed the water produced. The copper oxide was prepared from absolutely pure electrolytic copper, and the hydrogen was obtained from three distinct sources, as follows: First, from pure zinc and hydrochloric acid; second, by electrolysis, in a generator containing dilute hydrochloric acid and zinc-mercury amalgam; third, by the action of caustic potash solution upon sheet aluminum. The gas was dried and purified by passage through a system of tubes and towers containing potash, calcium chloride, glass beads drenched with sulphuric acid, and phosphorus pentoxide. No impurity could be discovered in it, and even nitrogen was sought for spectroscopically without being found.

The hydrogen was weighed in a glass globe holding nearly 5 liters and weighing 570.5 grammes, which was counterpoised by a second globe of exactly the same external volume. Before filling, the globe was exhausted to within 1 mm. of mercury and weighed. It was then filled with hydrogen and weighed again. The difference between the two weights gives the weight of hydrogen taken.

In burning, the hydrogen was swept from the globe into the combustion furnace by means of a stream of air which had previously been passed over hot reduced copper and hot cupric oxide, then through potash bulbs, and finally through a system of driers containing successively calcium chloride, sulphuric acid, and phosphorus pentoxide. The water formed by the combustion was collected in a condensing tube connected with a U tube containing phosphorus pentoxide. The latter was followed by a safety tube containing either calcium chloride or phosphorus pentoxide, added to the apparatus to prevent reflex diffusion. Full details as to the arrangement and construction of the apparatus are given. The final results appear in three series, representing the three sources from which the hydrogen was obtained. All weights are corrected to a vacuum.

First series.—Hydrogen from zinc and acid.

Wt. of H.	*Wt. H_2O.*	*Ratio H:O.*
.4233	3.8048	15.977
.4136	3.7094	15.937
.4213	3.7834	15.960
.4163	3.7345	15.941
.4131	3.7085	15.954
		Mean, 15.954±.0048

Second series.—Electrolytic hydrogen.

.4112	3.6930	15.962
.4089	3.6709	15.955
.4261	3.8253	15.955
.4197	3.7651	15.942
.4144	3.7197	15.953
		Mean, 15.953±.0022

Third series.—Hydrogen from caustic potash.

.42205	3.7865	15.943
.4284	3.8436	15.944
.4205	3.7776	15.967
.43205	3.8748	15.937
.4153	3.7281	15.954
.4167	3.7435	15.967
		Mean, 15.952±.0035
		Mean of all as one series, 15.953±.0020

Shortly after the appearance of this paper by Cooke and Richards Lord Rayleigh pointed out the fact, already noted by Agamennone, that a glass globe when exhausted is sensibly con-

[1] Proc. Amer. Acad., 23, 149. Amer. Chem. Journ., 10, 81.

densed by the pressure of the surrounding atmosphere. This fact involves a correction to the foregoing data, due to a change in the tare of the globe used, and this correction was promptly determined and applied by the authors.[1] By a careful series of measurements they found that the correction amounted to an average increase of 1.98 milligrams to the weight of hydrogen taken in each experiment. Hence O equals not 15.953, but 15.869, the probable error remaining unchanged. The final result of Cooke and Richards' investigation therefore is

$$O = 15.869 \pm .0020$$

Keiser's determinations of the ratio were published almost simultaneously with those of Cooke and Richards. He burned hydrogen occluded by palladium, and weighed the water so formed. In a preliminary paper[2] the following results are given:

Wt. of H.	*Wt. of H_2O.*	*Ratio H : O.*
.65100	5.81777	15.873
.60517	5.41540	15.897
.33733	3.00655	15.822
		Mean, 15.864 ± .015

Not long after the publication of the foregoing data Keiser's full paper appeared.[3] Palladium foil, warmed to a temperature of 250°, was saturated with hydrogen prepared from dilute sulphuric acid and zinc free from arsenic. From 100 to 140 grammes of palladium were taken, and it was first proved that the metal did not absorb other gases, which might contaminate the hydrogen. Before charging, the foil was heated to bright redness in vacuo. After charging, the tube containing the palladium hydride was exhausted by means of a Geissler pump to remove any nitrogen which might have been present. In the preliminary investigation cited above, the latter precaution was neglected, which may account for the low results.

Between the palladium tube and the combustion tube a U tube was interposed, containing phosphorus pentoxide. This was to determine the amount of moisture in the hydrogen. The combustion tube was filled with granular copper oxide, prepared by reducing the commercial oxide in hydrogen, heating the metal so obtained to bright redness in a vacuum, and then reoxidizing with pure oxygen.

Upon warming the palladium tube, which was first carefully weighed, hydrogen was given off and allowed to pass into the combustion tube. When the greater part of it had been burned the tube was cut off by means of a stopcock and allowed to cool. Meanwhile a stream of nitrogen was passed through the combustion tube, sweeping hydrogen before it. This was followed by a current of oxygen, reoxidizing the reduced copper; and the copper oxide was finally cooled in a stream of dry air. The water produced by the combustion was collected in a weighed bulb tube, followed by a weighed U tube containing phosphorus pentoxide.

A second phosphorus pentoxide tube served to prevent the sucking back of moisture from the external air. The loss in weight of the palladium tube, corrected by the gain in weight of the first phosphorus pentoxide, gave the weight of hydrogen taken. The gain in weight of the two collecting tubes gave the weight of water formed. All weights in the following table of results are reduced to a vacuum:

Wt. of H.	*Wt. H_2O.*	*Ratio H : O.*
0.34145	3.06338	15.943
.68394	6.14000	15.955
.65529	5.88200	15.952
.65295	5.86206	15.954
.66664	5.98116	15.944
.66647	5.98341	15.955
.57967	5.20493	15.958
.66254	5.94758	15.952
.87770	7.86775	15.950
.77215	6.93036	15.951
		Mean, 15.9514 ± .0011

[1] Proc. Amer. Acad., 23, 182. Amer. Chem. Journ., 10, 191. [2] Berichte, 20, 2323. 1887. [3] Amer. Chem. Journ., 10, 249. 1888.

In sum, 6.55880 grammes of hydrogen gave 52.30383 of water, whence O = 15.9492.

In March, 1889, Lord Rayleigh[1] published a few determinations of the ratio obtained by still a new method. Pure hydrogen and pure oxygen were both weighed in glass globes. From these they passed into a mixing chamber, and thence into a eudiometer, where they were gradually exploded by a series of electric sparks. After explosion, the residual gas remaining in the eudiometer was determined and measured. The results, given without weighings or explicit details, are as follows:

15.93	15.93
15.98	15.92
15.98	

Mean, 15.948 ± .009

Correcting this result for shrinkage of the globes and consequent change of tare, it becomes O = 15.89, ± .009.

In the same month that Lord Rayleigh's paper appeared, W. A. Noyes[2] published his first series of determinations. His method was to pass hydrogen into an apparatus containing hot copper oxide, condensing the water formed in the same apparatus, and from the gain in weight of the latter getting the weight of the hydrogen absorbed. The apparatus devised for this purpose consisted essentially of a glass bulb of 30 to 50 cc. capacity, with a stopcock tube on one side and a sealed condensing tube on the other. In weighing, it was counterpoised by another apparatus of nearly the same volume, but somewhat less weight, in order to obviate reductions to a vacuum. After filling the bulb with commercial copper oxide (90 to 150 grammes), the apparatus was heated in an air bath, exhausted by means of a Sprengel pump, cooled, and weighed. It was next replaced in the air bath, again heated, and connected with an apparatus delivering purified hydrogen. When a suitable amount of the latter had been admitted, the stopcock was closed, and the heating continued long enough to convert all gaseous hydrogen within it into water. The apparatus was then cooled and weighed, after which it was connected with a Sprengel pump, in order to extract the small quantity of nitrogen which was always present. The latter was pumped out into a eudiometer, where it was measured and examined. The gain in weight of the apparatus, less the weight of this very slight impurity, gave the weight of hydrogen oxidized.

The next step in the process consisted in heating the apparatus to expel water, and weighing again. After this, pure oxygen was admitted and the heating was resumed, so as to oxidize the traces of hydrogen which had been retained by the copper. Again the apparatus was cooled and weighed, and then reheated, when the water formed was received in a bulb filled with phosphorus pentoxide, and the gaseous contents were collected in a eudiometer. On cooling and weighing the apparatus, the loss of weight less the weight of gases pumped out, gave the amount of water produced by the traces of residual hydrogen under consideration. This weight, added to the loss of weight when the original water was expelled, gives the weight of oxygen taken away from the copper oxide. Having thus the weight of hydrogen and the weight of oxygen, the ratio sought for follows. Six results are given, but as they are repeated, with corrections, in Noyes' second paper, they need not be considered now.

Noyes' methods were almost immediately criticized by Johnson,[3] who suggested several sources of error. This chemist had already shown in an earlier paper[4] that copper reduced in hydrogen persistently retains traces of the latter, and also that when the reduction is effected below 700°, water is retained too. The possible presence of sulphur in the copper oxide was furthermore mentioned. Errors from these sources would tend to make the apparent atomic weight of oxygen (referred to hydrogen as unity) too low.

In his second paper[5] Noyes replies to the foregoing criticisms, and shows that they carry no weight, at least so far as his work is concerned. He also describes a number of experiments in which oxides other than copper oxide were tried, but without distinct success, and he gives fuller details as to manipulations and materials. His final results are in four series, as follows:

[1] Proc. Roy. Soc., 45, 425.
[2] Amer. Chem. Journ., 11, 155. 1889.
[3] Chem. News, 59, 272.
[4] Journ. Chem. Soc., May, 1879.
[5] Amer. Chem. Journ., 12, 441. 1890.

First Series.—Hydrogen from Zinc and Hydrochloric Acid.

Wt. of H.	*Wt. of O.*	*Ratio H : O.*
.9443	7.5000	15.885
.6744	5.3555	15.882
.7866	6.2569	15.909
.5521	4.3903	15.904
.4274	3.3997	15.909
.8265	6.5686	15.895
		Mean, 15.8973 ± .0032

This series appeared in the earlier paper, but with an error which is here corrected.

Second Series.—Electrolytic Hydrogen, Dried by Phosphorus Pentoxide.

Wt. of H.	*Wt. of O.*	*Ratio H : O.*
0.5044	4.0095	15.898
.6325	5.0385	15.932
.6349	5.0517	15.913
.5564	4.4175	15.879
.7335	5.8224	15.876
.6696	5.3181	15.885
		Mean, 15.8971±0.0064

Third Series.—Electrolytic Hydrogen, Dried by Passage Through a Tube Packed with Sodium Wire.

Wt. of H.	*Wt. of O.*	*Ratio H : O.*
0.9323	7.4077	15.891
.9952	7.9045	15.885
.3268	2.5977	15.898
.7907	6.2798	15.884
.7762	6.1671	15.891
1.1221	8.9131	15.887
		Mean, 15.8893±0.0014

At the end of this series it was found that the hydrogen contained a trace of water, estimated to be equivalent to an excess of 3 milligrams in the total hydrogen of the six experiments. Correcting for this, the mean becomes O = 15.899.

Fourth Series.—Electrolytic Hydrogen, Dried over Freshly Sublimed Phosphorus Pentoxide.

Wt. of H.	*Wt. of O.*	*Ratio H : O.*
1.0444	8.3017	15.898
.7704	6.1233	15.896
.8231	6.5421	15.896
.8872	7.0490	15.890
.9993	7.9403	15.892
1.1910	9.4595	15.885
		Mean, 15.8929±0.0013

The mean of all the 24 determinations, taken as one series, with the correction to the third series included, is O = 15.8966 ± 0.0017. In sum, there were consumed 18.5983 grammes of hydrogen and 147.8145 of oxygen; whence O = 15.8955.

Dittmar and Henderson,[1] who effected the synthesis of water over copper oxide by what was essentially the old method, begin their memoir with an exhaustive criticism of the work done by Dumas and by Erdmann and Marchand. They show, as I have already mentioned, that hydrogen dried by sulphuric acid becomes contaminated with sulphur dioxide, and also that a gas passed over calcium chloride may still retain as much as 1 milligramme of water per liter. Fused caustic potash they found to dry a gas quite completely.

[1] Proc. Roy. Soc. Glasgow, 22, 33. Communicated Dec. 17, 1890.

In their first series of syntheses, Dittmar and Henderson generated their hydrogen from zinc and acid, sometimes hydrochloric and sometimes sulphuric, and dried it by passage first through cotton wool, then through vitrioled pumice, then over red-hot metallic copper to remove oxygen. In later experiments it first traversed a column of fragments of caustic soda to remove antimony derived from the zinc. The oxide of copper used was prepared by heating chemically pure copper clippings in a muffle, and was practically free from sulphur. In weighing the several portions of apparatus it was tared with somewhat lighter similar pieces of as nearly as possible the same displacement. The results of this series of experiments, which are vitiated by the presence, unsuspected at first, of sulphur dioxide in the hydrogen, are stated in values of H when O = 16, but in the following table have been recalculated to conformity with the earlier determinations:

Wt. of water.	*Wt. of O.*	*Ratio H : O.*
4.7980	4.26195	15.901
7.55025	6.71315	16.039
6.2372	5.53935	15.875
11.29325	10.03585	15.963
11.6728	10.3715	15.940
11.8433	10.5256	15.976
11.7317	10.4243	15.947
19.2404	17.0926	15.916
20.83435	18.5234	16.031
17.40235	15.4598	15.917
19.2631	17.11485	15.934
		Mean, 15.949 ± 0.0103

Reducing to a vacuum, this becomes 15.843, while a correction for the sulphur dioxide estimated to be present in the hydrogen brings the value up again to 15.865. Still another correction is suggested, namely, that as the reduced copper in the combustion tube, before weighing, was exposed to a long-continued current of dry air, it may have taken up traces of oxygen chemically, thereby increasing its weight. As this correction, however, is quantitatively uncertain, it may be neglected here, and the result of this series will be taken as O = 15.865 ± 0.0103. Its weight, relatively to that of some other series of experiments, is evidently small.

In their second and final series Dittmar and Henderson dried their hydrogen, after deoxidation by red-hot copper, over caustic potash and subsequently phosphorus pentoxide. The copper oxide and copper of the combustion tube were both weighed in vacuo. The results were as follows, vacuum weights being given:

Wt. of water.	*Wt. of O.*	*Ratio H : O.*
19.2057	17.0530	15.843
19.5211	17.3342	[15.853]
19.4672	17.2882	15.868
22.9272	20.3540	15.820
23.0080	20.4421	[15.934]
23.4951	20.8639	15.859
23.5612	20.9226	[15.859]
23.7542	21.0957	15.870
23.6568	21.8994	15.884
23.6179	21.8593	15.848
24.6021	21.8499	15.878
24.3047	21.5788	15.832
23.6172	20.9709	15.849
		Mean, 15.861 ± 0.0052

The authors reject the three bracketed determinations, because of irregularities in the course of the experiments. The mean of the 10 remaining determinations is 15.855 ± 0.0044. Both means, however, have to be corrected for the minute trace of hydrogen occluded by the reduced copper. This correction, experimentally measured, amounts to +0.006. Hence the mean of

all the experiments in the series becomes 15.867 ± 0.0052, and of the 10 accepted experiments 15.861 ± 0.0044. The authors themselves select out seven experiments, giving a corrected mean of 15.866, which they regard as the best value. Taking all their evidence, their two series combine thus:

First series	15.865 ±0.0103
Second series	15.867 ± .0052
General mean	15.8667± .0046

Leduc,[1] who also effected the synthesis of water over copper oxide, following Dumas's method with slight modifications, gives the results of two experiments, as follows:

Wt. Water.	*Wt. O.*	*Ratio H:O.*
22.1632	19.6844	15.882
19.7403	17.5323	15.880
		Mean, 15.881

These experiments we may arbitrarily assign equal weight with two in Dittmar and Henderson's later series, when the result becomes 15.881, ±.0132, the value to be accepted. Leduc states that his copper oxide, which was reduced at as low a temperature as possible, was prepared by heating clippings of electrolytic copper in a stream of oxygen.

To E. W. Morley[2] we owe the first complete quantitative syntheses of water, in which both gases were weighed separately, and afterwards in combination. The hydrogen was weighed in palladium, as was done by Keiser, and the oxygen was weighed in compensated globes, after the manner of Regnault. The globes were contained in an artificial "cave," to protect them from moisture and from changes of temperature; being so arranged that they could be weighed by the method of reversals without opening either the "cave" or the balance case. For each weighing of hydrogen about 600 grammes of palladium were employed. After weighing, the gases were burned by means of electric sparks in a suitable apparatus, from which the unburned residue could be withdrawn for examination. Finally, the apparatus containing the water produced was closed by fusion and also weighed. Rubber joints were avoided in the construction of the apparatus, and the connections were continuous throughout. The weights and derived ratios are as follows:

H taken.	*O taken.*	*H_2O formed.*	*H:O.*	*$H:H_2O$.*
3.2645	25.9176	29.1788	15.878	17.877
3.2559	25.8531	29.1052	15.881	17.878
3.8193	30.3210	34.1389	15.878	17.873
3.8450	30.5294	lost	15.880	.....
3.8382	30.4700	34.3151	15.877	17.881
3.8523	30.5818	34.4327	15.877	17.876
3.8298	30.4013	34.2284	15.877	17.875
3.8286	30.3966	34.2261	15.878	17.879
3.8225	30.3497	34.1742	15.879	17.881
3.8220	30.3479	34.1743	15.881	17.883
3.7637	29.8865	33.6540	15.881	17.883
3.8211	30.3429	34.1559	15.882	17.878
			Mean, 15.8792, ±.00032	17.8785, ±.00066

Combined, these data give:

From ratio H:O	15.8792, ± .00032
From ratio $H:H_2O$	15.8785, ± .00066
General mean	15.8790, ± .00028

[1] Compt. Rend., 115, 41. 1892. See also the complete memoir in Ann. Chim. Phys. (7), 15, 48. 1898. In the latter Leduc gave a preliminary determination which made O=15.860.

[2] "On the Density of Oxygen and Hydrogen, and on the Ratio of their Atomic Weights," by Edward W. Morley. Smithsonian Contributions to Knowledge, 29, 1895, 4to, xi + 117 pp., 40 cuts. Abstract in Am. Chem. Journ., 17, 267 (gravimetric), and Ztschr. phys. Chem., 17, 87 (gaseous densities); also note in Am. Chem. Journ., 17, 396. Preliminary notice in Proc. Amer. Association, 1891, p. 185. See also a discussion by Morley of all the earlier determinations, in the Western Reserve University Bulletin, for April, 1895.

For details Morley's original memoir must be consulted. No abstract can do full justice to it.

Two other series of determinations, by Julius Thomsen, are radically different in method from all the previous work. In the first series[1] he determined the ratio between HCl and NH_3; and thence, using Stas' values for Cl and N, fixed by reference to O = 16, computed the ratio H : O. This method was so indirect as to be of little importance, and gave for the atomic weight of oxygen approximately the round number 16. I shall use the data further on for another purpose. The paper has been sufficiently criticised by Meyer and Seubert,[2] who have discussed its sources of error. The ratio has also been studies by Baume and Perrot; whose work will be considered in another section, later.

In Thomsen's later memoir[3] a method of determination is described which is, like the preceding, quite novel, but more direct. First, aluminum, in weighed quantities, was dissolved in caustic potash solution. In one set of experiments the apparatus was so constructed that the hydrogen evolved was dried and then expelled. The loss of weight of the apparatus gave the weight of the hydrogen so liberated. In the second set of experiments the hydrogen passed into a combustion chamber in which it was burned with oxygen, the water being retained. The increase in weight of this apparatus gave the weight of oxygen so taken up. The two series, reduced to the standard of a unit weight of aluminum, gave the ratio between oxygen and hydrogen.

The results of the two series, reduced to a vacuum and stated as ratios, are as follows:

First. $\frac{\text{Weight of H}}{\text{Weight of Al}}$	*Second.* $\frac{\text{Weight of O}}{\text{Weight of Al}}$
0.11180	0.88788
0.11175	0.88799
0.11194	0.88774
0.11205	0.88779
0.11189	0.88785
0.11200	0.88789
0.11194	0.88798
0.11175	0.88787
0.11190	0.88773
0.11182	0.88798
0.11204	0.88785
0.11202	
0.11204	0.88787, ± 0.000018
0.11179	
0.11178	
0.11202	
0.11188	
0.11186	
0.11185	
0.11190	
0.11187	
0.11190, ± 0.000015	

Dividing the mean of the second column by the mean of the first, we have for the equivalent of oxygen:

$$\frac{0.88787,\ \pm 0.000018}{0.11190,\ \pm 0.000015} = 7.9345,\ \pm 0.0011$$

Hence O = 15.8690, ±0.0022.

The details of the investigation are somwhat complicated and involve various corrections which need not be considered here. The result as finally stated includes all corrections and is evidently good.

[1] Zeitsch. physikal Chem., 13, 398. 1894.
[2] Ber. Deutsch. chem. Ges., 27, 2770. See also Acree and Brunel, Amer. Chem. Journ., 36, 117.
[3] Zeitsch. anorg. Chem., 11, 14. 1895.

The syntheses of water reported by Keiser[1] in 1898, involved the direct oxidation of hydrogen occluded in palladium, with subsequent weighing of the water so produced in the vessel in which it was generated. That vessel was tubular in form, and divided into two compartments; one containing phosphorus pentoxide, to absorb the water, the other holding the palladium hydride. Each determination required five weighings, as follows: First, of the vessel, containing only the drying agent, and exhausted of air. Second, the same as the first, plus the palladium. Third, the gain in weight was measured after saturating the palladium with hydrogen. Fourth, the entire apparatus after complete oxidation of the hydrogen to water. The gain in weight gave the oxygen absorbed. Fifth, like the fourth, but with the palladium removed. The difference between the first and fifth weighings gave the amount of water formed. All the operations were thus performed in a single piece of apparatus, and troublesome corrections were avoided. The data obtained were as follows, with weights not reduced to a vacuum:

H taken.	*O taken.*	*H_2O formed.*	*H:O.*	*H:H_2O.*
.27549	2.18249	2.45975	15.8444	17.8573
.27936	2.21896	2.49923	15.8860	17.8925
.27091	2.15077	2.42355	15.8781	17.8919
.26845	2.13270	2.40269	15.8890	17.9005
			Mean, 15.8744	15.8855

Taken as one series, the two sets of values, eight determinations in all, give for the ratio H : O the number $15.8799 \pm .0046$. This figure is slightly higher than Morley's average, but below his maximum.

Late in 1907, an elaborate investigation by Noyes[2] was published, covering five series of syntheses. The first series of 20 experiments, however, was found to be affected by a small constant error, and it was therefore rejected. The other series gave the subjoined results, with all corrections, including the reduction to a vacuum, applied.

Second series.—Electrolytic hydrogen, from sulphuric acid, was weighed in palladium, and again in the copper oxide tube in which it was oxidized to water. The apparatus was similar to that used in his former research, and so, too, but with differences in detail, was the procedure.

H taken.	*O taken.*	*H_2O formed.*	*H : O.*	*H : H_2O.*
3.72565	29.57891	33.30408	15.8785	17.8783
3.80318	30.18400	33.98748	15.8730	17.8732
3.75873	29.83358	33.59127	15.8743	17.8737
2.96328	23.5197	26.48379	15.8742	17.8746
2.11395	lost	18.89214	.....	17.8734
3.53136	28.02910	31.56024	15.8744	17.8743
3.53959	28.09619	31.63554	15.8754	17.8753
			Mean, 15.8750	17.8747
			±.00052	±.00045

Third series.—Hydrogen from sulphuric acid was passed directly into the copper oxide bulb and there converted into water.

H taken.	*O taken.*	*H_2O formed.*	*H : O.*	*H : H_2O.*
2.44279	19.39757	21.84042	15.8813	17.8815
2.18739	17.36305	19.55117	15.8756	17.8763
2.75129	21.84345	24.59389	15.8787	17.8781
4.00062	.....	35.75083	.....	17.8726
4.04057	32.07689	36.11762	15.8774	17.8775
			Mean, 15.8782	17.8772
			±.00091	±.00097

[1] Amer. Chem. Journ., 20, 733. 1898.

[2] Amer. Chem. Journ., 29, 1718. 1907. In Vol. 30, p. 4, 1908, Noyes discusses all determinations of the atomic weight of hydrogen, and proposes criteria for the rejection of doubtful data.

Fourth series.—Hydrogen and oxygen, both obtained by electrolysis of sulphuric acid, were directly combined by means of palladium, somewhat as in Keiser's determinations. The use of copper oxide was thus avoided.

H taken.	*O taken.*	*H_2O formed.*	*H : O.*	*H : H_2O.*
2.27916	18.08455	20.36128	15.8695	17.8674
4.12734	32.76527	36.89043	15.8772	17.8761
4.17556	33.13449	37.30787	15.8707	17.8696
4.19346	33.27384	37.46453	15.8694	17.8681
2.30746	18.30863	20.61357	15.8691	17.8669
4.59692	36.48543	41.08162	15.8739	17.8735
4.63625	36.79354	41.42905	15.8721	17.8718
4.57274	36.28696	40.85834	15.8710	17.8704
		Mean,	15.8716	17.8705
			±.00066	±.00074

Fifth series.—Essentially like series four, except that the two gases were prepared by electrolysis of barium hydroxide.

H taken.	*O taken.*	*H_2O formed.*	*H : O.*	*H : H_2O.*
4.61180	36.60909	41.22105	15.8763	17.8763
4.62358	36.69575	41.31647	15.8733	17.8721
4.59853	36.50484	41.10212	15.8768	17.8762
4.55832	36.17887	40.73904	15.8738	17.8746
4.20399	33.37000	37.57336	15.8754	17.8751
		Mean,	15.8751	17.8749
			±.00046	±.00051

Since these series of measurements represent different methods, and are evidently of unequal value, it is best to combine them mathematically, giving each mean a weight inversely proportional to the square of its probable error. Noyes computed all of the experiments on the basis of the oxygen standard, giving for each one its expression as the atomic weight of hydrogen. I have chosen the present form for simplicity of calculation, and for greater ease of combination with previous determinations.[1]

	Ratio H:O.	*Atomic weight H.*
Series 2. H : O	15.8750±.00052	1.00787
H : H_2O	15.8747±.00045	1.00789
Series 3. H : O	15.8782±.00091	1.00767
H : H_2O	15.8772±.00097	1.00774
Series 4. H : O	15.8716±.00066	1.00809
H : H_2O	15.8705±.00074	1.00815
Series 5. H : O	15.8751±.00046	1.00786
H : H_2O	15.8749±.00051	1.00788
General mean	15.8745±.00021	1.00783±.000013

The details of Noyes' investigation are too voluminous for repetition here. It goes almost without saying that every precaution was taken which his own previous experience and the experience of others could suggest, and that his materials were of the highest degree of purity. The true value of the ratio must lie somewhere within the range of variation shown by his individual determinations, which it may be observed, overlap those of Morley.

We have now before us, for combination, 15 sets of determinations of the hydrogen-oxygen ratio. I have arranged them in the order of descending magnitude, and computed their general mean as follows:

[1] See Noyes' memoir for the results of combining his data in different ways. The 48 experiments, taken as one series, give H = 1.00793, ± .00002.
Referring to his determinations published in 1890, Noyes points out a constant error in them, the elimination of which reduces the value of the ratio to 15.879, in agreement with the measurements by Morley.

	Ratio.	*Atomic weight H.*
1. Erdmann and Marchand	15.975 ±.0113	1.00156
2. Dumas	15.9607±.0070	1.00246
3. Keiser, 1888	15.9514±.0011	1.00305
4. Thomsen, 1870	15.91 ±.0113	1.00565
5. Noyes, 1890, uncorrected	15.8966±.0017	1.00650
6. Dulong and Berzelius	15.894 ±.0570	1.00667
7. Rayleigh	15.89 ±.0090	1.00692
8. Leduc	15.881 ±.0132	1.00750
9. Keiser, 1898	15.8799±.0046	1.00756
10. Morley	15.8790±.00028	1.00762
11. Noyes, 1907	15.8745±.00021	1.00783
12. Cooke and Richards	15.8690±.0020	1.00825
13. Thomsen, 1895	15.8690±.0022	1.00825
14. Dittmar and Henderson	15.8677±.0046	1.00834
15. Keiser, 1887	15.864 ±.0150	1.00857
General mean	15.8779±.00016	1.00769±.00001

In this combination, which includes all the syntheses, good or bad, the general mean lies between the values found by Noyes and Morley. It is, therefore, not far from the truth. If we reject the high values, Nos. 1 to 7, the general mean becomes 15.8760±.00017, and H=1.00781±.00001. Values 10 and 11, combined, give 15.8761±.00017, and H=1.00780±.00001. That is, the Morley and Noyes determinations control all the others, and practically eliminate them. The high and low figures tend to balance one another, and so to disappear from the final combination.

In discussing the relative densities of oxygen and hydrogen gases we need consider only the more modern determinations, beginning with those of Dumas and Boussingault. As the older work has some historical value, I may in passing just cite its results. For the density of hydrogen we have .0769, Lavoisier; .0693, Thomson; .092, Cavendish; .0732, Biot and Arago; .0688, Dulong and Berzelius. For oxygen there are the following determinations: 1.087, Fourcroy, Vauquelin, and Séguin; 1.103, Kirwan; 1.128, Davy; 1.088, Allen and Pepys; 1.1036, Biot and Arago; 1.1117, Thomson; 1.1056, De Saussure; 1.1026, Dulong and Berzelius; 1.106, Buff; 1.1052, Wrede.[1]

In 1841 Dumas and Boussingault[2] published their determinations of gaseous densities. For hydrogen they obtained values ranging from .0691 to .0695; but beyond this mere statement they give no details. For oxygen three determinations were made, with the following results:

1.1055
1.1058
1.1057

Mean, 1.10567±.00006

If we take the two extreme values given above for hydrogen, and regard them as the entire series, they give us a mean of .0693±.00013. This mean hydrogen value, combined with the mean for oxygen, gives for the latter, when H=1, the density ratio 15.9538±.031.

Regnault's researches, published four years later,[3] were much more elaborately executed. Indeed, they long stood among the classics of physical science, and it is only recently that they have been supplanted by other measurements.

For hydrogen three determinations of density gave the following results:

.06923
.06932
.06924

Mean, .069263±.000019

[1] For Wrede's work, see Berzelius' Jahresbericht for 1843. For Dulong and Berzelius, see the paper already cited. All other determinations are taken from Gmelin's Handbook, Cavendish edition, v. 1, p. 279.

[2] Compt. Rend., 12, 1005. Compare also with Dumas, Compt. Rend., 14, 537.

[3] Compt. Rend., 20, 975.

For oxygen four determinations were made, but in the first one the gas was contaminated by traces of hydrogen, and the value obtained, 1.10525, was, therefore, rejected by Regnault as too low. The other three are as follows:

1.10561
1.10564
1.10565

Mean, 1.105633 ± .000008

Now, combining the hydrogen and oxygen series, we have the ratio H: O: : 1: 15.9628 ± .0044. According to Le Conte,[1] Regnault's reductions contain slight numerical errors, which, corrected, give for the density of oxygen, 1.105612, and for hydrogen, .069269. Ratio, 1: 15.9611.

A much weightier correction to Regnault's data has already been indicated in the discussion of Cooke and Richards's work. He assumed that the globes in which the gases were weighed underwent no changes of volume, but Agamennone,[2] and after him, but independently,[3] Lord Rayleigh showed that an exhausted vessel was perceptibly compressed by atmospheric pressure. Hence its volume when empty was less than its volume when filled with gas. Crafts having access to Regnault's original apparatus has determined the magnitude of the correction thus indicated.[4] Unfortunately, the globe actually used by Regnault had been destroyed, but another globe of the same lot was available. With this the amount of shrinkage during exhaustion was measured, and Regnault's densities were thereby changed to 1.10562 for oxygen and .06949 for hydrogen. Corrected ratio, 1: 15.9105. Doubtless Dumas and Boussingault's data are subject to a similar correction, and if we assume that it is proportionally the same in amount, the ratio derived from their experiments becomes 1: 15.9015.

In the same paper, that which contained the discovery of this correction, Lord Rayleigh gives a short series of measurements of his own. His hydrogen was prepared from zinc and sulphuric acid, and was purified by passage over liquid potash, then through powdered mercuric chloride, and pulverized solid potash successively. It was dried by means of phosphorus pentoxide. His oxygen was derived partly from potassium chlorate, and partly from the mixed chlorates of sodium and potassium. Equal volumes of the two gases weighed as follows:

H.	*O.*
.15811	2.5186 ± .00061[5]
.15807	
.15798	
.15792	
Mean, .15802 ± .000029	

Corrected for shrinkage of the exhausted globe these become—H, 0.15860; O, 2.5192. Hence the ratio 1: 15.884 ± .0048.

In 1892 Rayleigh published a much more elaborate determination of this ratio.[6] The gases were prepared electrolytically from caustic potash, and dried by means of solid potash and phosphorus pentoxide. The hydrogen was previously passed over hot copper. The experiments, stated like the previous series, are in five groups; two for oxygen and three for hydrogen; but for present purposes the similar sets may be regarded as equal in weight, and so discussable together. The weights of equal volumes are as follows·

	H.	*O.*	
First set	.15807	2.5182	
	.15816	2.5173	
	.15811	2.5172	First set
Mean, .15808	.15803	2.5193	Mean, 2.51785
	.15801	2.5174	
	.15809	2.5177	

[1] Private communication. See also Phil. Mag. (4), 27, 29, 1864, and Smithsonian Report, 1878, p. 428.
[2] Atti Rendiconti Acad. Lincei, 1885.
[3] Proc. Roy. Soc., 43, 356. Feb., 1888.
[4] Compt. Rend., 106, 1662.
[5] Arbitrarily assigned the probable error of a single experiment in Rayleigh's paper of 1892.
[6] Proc. Roy. Soc., 50, 448, Feb. 18, 1892.

	H.	*O.*	
Second set Mean, .15797	.15800	2.5183	
	.15820	2.5168	
	.15792	2.5172	Second set
	.15788	2.5181	Mean, 2.5172
	.15783	2.5156	
	.15807		
Third set Mean, .15804	.15801		
	.15817		
	.15790		
	.15810		
	.15798		
	.15802		
	.15807		
	Mean, .15804 ± .000019	Mean, 2.5176 ± .00019	

These weights with various corrections relative to temperatures and pressures, and also for the compression of the exhausted globe, ultimately become for H, .158531; and for O, 2.51777. Hence the ratio 1: 15.882 ± .0023. For details relative to corrections the original memoir should be consulted.

In his paper "On a new method of determining gas densities," [1] Cooke gives three measurements for hydrogen, referred to air as unity. They are:

.06957
.06951
.06966

Mean, .06958 ± .000029

Combining this with Regnault's density for oxygen, as corrected by Crafts, 1.10562, ± .000008, we get the ratio H : O : : 1 : 15.890 ± .0067.

Leduc, working by Regnault's method, somewhat modified, and correcting for shrinkage of exhausted globes, gives the following densities:[2]

H.	*O.*
.06947	1.10501
.06949	1.10516
.06947	
Mean, .06948 ± .00006745	

The two oxygen measurements are the extremes of three, the mean being 1.10506 ± .0000337. Hence the ratio 1 : 15.905, ± .0154.

In a later memoir Leduc [3] gives two more measurements of the density of oxygen. They are 1.10527 and 1.10521. If we include these in series with the other values the mean becomes 1.10514 ± .0000321. The use of this figure in subsequent combinations of data has an insignificant effect upon the computations. It raises O from 15.905 to 15.906.

The first two hydrogen determinations were made with gas produced by the electrolysis of caustic potash, while the third sample was derived from zinc and sulphuric acid. The oxygen was electrolytic. Both gases were passed over red-hot platinum sponge, and dried by phosphorus pentoxide.

Much more elaborate determinations of the two gaseous densities are those made by Morley.[4] For oxygen he gives three series of data; two with oxygen from potassium chlorate, and one with gas partly from the same source and partly electrolytic. In the first series, temperature and pressure were measured with a mercurial thermometer and a mano-barometer. In the second series they were not determined for each experiment, but were fixed by comparison with a standard volume of hydrogen by means of a differential manometer. In the third series the gas was kept at the temperature of melting ice, and the mano-barometer alone

[1] Proc. Amer. Acad., 24, 202. 1889. Also Am. Chem. Journ., 11, 509.
[2] Compt. Rend., 113, 186. 1891
[3] Ann. Chim. Phys. (7), 15, 29. 1898. In C. R., 148, 42, Leduc claims that the probable error of his H is only ± .00001.
[4] Paper already cited, in the synthetic portion of this chapter.

was read. The results for the weight in grammes, at latitude 45°, of one liter of oxygen are as follows:

First Series.	*Second Series.*	*Third Series.*
1. 42864	1. 42952	1. 42920
1. 42849	1. 42900	1. 42860
1. 42838	1. 42863	1. 42906
1. 42900	1. 42853	1. 42957
1. 42907	1. 42858	1. 42910
1. 42887	1. 42873	1. 42930
1. 42871	1. 42913	1. 42945
1. 42872	1. 42905	1. 42932
1. 42883	1. 42896	1. 42908
	1. 42880	1. 42910
Mean, 1. 42875 ± . 000051	1. 42874	1. 42951
Corrected,[1] 1. 42879 ± . 000051	1. 42878	1. 42933
	1. 42872	1. 42905
	1. 42859	1. 42914
	1. 42851	1. 42849
		1. 42894
Mean, 1. 42882 ± . 000048		1. 42886
Corrected, 1. 42887 ± . 000048		
Mean, 1. 42912 ± . 000048		
Corrected, 1. 42917 ± . 000048		

General mean of all three series, 1.42896 ± .000028.

Morley himself, for experimental reasons, prefers the last series, and gives it double weight, getting a mean density of 1.42900. The difference between this mean and that given above is insignificant with reference to the atomic weight problem.

In the case of hydrogen, Morley's determinations fall into two groups, but in both the gas was prepared by the electrolysis of pure dilute sulphuric acid, and was most elaborately purified. In the first group there are two series of measurements. Of these, the first involved the reading of temperature and pressure by means of a mercurial thermometer and manobarometer. In the second series, the gas was delivered into the weighing globes after occlusion in palladium; it was then kept at the temperature of melting ice, and only the siphon barometer was read. In this group the hydrogen was possibly contaminated with mercurial vapor, and the results are discarded by Morley in his final summing up. For present purposes, however, it is unnecessary to reject them, for they have confirmatory value, and do not appreciably affect the final mean. The weight of one liter of hydrogen at 45° latitude, as found in these two sets of determinations, is as follows:

First Series.	*Second Series.*
0. 089904	0. 089977
. 089936	. 089894
. 089945	. 089987
. 089993	. 089948
. 089974	. 089951
. 089941	. 089960
. 089979	. 090018
. 089936	. 089909
. 089904	. 089953
. 089863	. 089974
. 089878	. 089922
. 089920	. 090093
. 089990	. 090007
. 089926	. 089899
. 089928	. 089974
	. 089900
Mean, . 089934 ± . 000007	. 089869
Corrected, . 089938 ± . 000007	. 090144
	. 089984
	Mean, . 089967 ± . 000011
	Corrected, . 089970 ± . 000011

[1] Correction applied by Morley to all his series, for a slight error, $\frac{1}{20000}$, in the length of his standard meter bar.

In the second group of experiments, the hydrogen was weighed in palladium before transfer to the calibrated globe; and in weighing, the palladium tube was tared by a similar apparatus of nearly equal volume and weight. After transfer, which was affected without the intervention of stopcocks, the volume and pressure of the gas were taken at the temperature of melting ice. A preliminary set of measurements was made, followed by three regular series; of these, the first and second were with the same apparatus, and are different only in point of time, a vacation falling between them. The last series was with a different apparatus. The data are as follows, with the means as usual:

Preliminary.	*Third Series.*	*Fourth Series.*	*Fifth Series.*
. 089946	. 089874	. 089972	. 089861
. 089915	. 089891	. 089877	. 089877
. 089881	. 089886	. 089867	. 089870
. 089901	. 089866	. 089916	. 089867
. 089945	. 089911	. 089770	. 089839
———	. 089856	. 089846	. 089874
Mean, . 089918,	. 089912	———	. 089864
± . 0000271	. 089872	Mean, . 089875,	. 089883
Corrected, . 089921	———	± . 0000187	. 089830
	Mean, . 089883,	Corrected, . 089880	. 089877
	± . 0000049		. 089851
	Corrected, . 089886		———
			Mean, . 089863,
			± . 0000034
			Corrected, . 089866

Now, rejecting nothing, we may combine all the series into a general mean, giving the weight of one liter of hydrogen as follows:

First series	0. 089938 ± 0. 000007
Second series	. 089970 ± . 000011
Preliminary series, second method	. 089921 ± . 0000271
Third series	. 089886 ± . 0000049
Fourth series	. 089880 ± . 0000187
Fifth series	. 089866 ± . 0000034
General mean	. 089897 ± . 0000025
Rejecting the first three	. 089872 ± . 0000028

This least mean value for hydrogen will be used in succeeding chapters of this work for reducing volumes of the gas to weights. Combining the general mean of all with the value found for the weight of a liter of oxygen, 1.42896, ± .000028, we get for the ratio H : O.

$$O = 15.8955 \pm 0.0005$$

If we take only the second mean for H, excluding the first three series, we have—

$$O = 15.9001 \pm 0.0005$$

The value is undoubtedly nearest the truth, and is preferable to all other determinations of the density ratio. Its probable error, however, is given too low; for some of the oxygen weighings involved reductions for temperature and pressure. These reductions involve, again, the coefficient of expansion of the gas, and its probable error should be included. Since, however, that factor has been disregarded elsewhere, it would be an over-refinement of calculation to include it here. Other corrections, of a mathematical character, have been recently applied to Morley's data by Guye and Mallet.[1] They find for the normal weight of 1 liter of each gas, O = 1.42886, and H = 0.089875. The difference between these figures and those given by Morley is so small as to be negligible.

Still more recently, by a novel method, J. Thomsen has measured the two densities in question.[2] In his gravimetric research, already cited, he ascertained the weights of hydrogen and of

[1] Compt. Rend., 138, 1034. 1904.

[2] Zeitsch. anorg. Chem., 12, 4. 1896.

oxygen equivalent to a unit weight of aluminum. In his later paper he describes a method of measuring the corresponding volumes of both gases during the same reactions. Then, having already the weights of the gases, the volume-weight ratio, or density, is in each case easily computable. From 1.0171 to 2.3932 grams of aluminum were used in each experiment. Omiting details, the volume of hydrogen in liters, equivalent to 1 gramme of the metal, is as follows:

1.24297	1.24283
1.24303	1.24260
1.24286	1.24314
1.24271	1.24294

Mean, 1.24289 ± 0.00004.

The weight of hydrogen evolved from 1 gramme of aluminum was found in Thomsen's gravimetric research to be 0.11190 ± 0.000015. Hence the weight of 1 liter at 0°, 760 mm., and 10.6 meters above sea level at Copenhagen is:

$$0.090032 \pm 0.000012$$

or at sea level in latitude 45°,

$$0.089947 \pm 0.000012 \text{ gram.}$$

The data for oxygen are given in somewhat different form, namely, for the volume of 1 gramme of the gas 0°, 760, and at Copenhagen. The values are, in liters:

0.69902
.69923
.69912
.69917
.69903
.69900
.69901
.69921
.69922

Mean, $.69910 \pm 0.00002$
At sea level in latitude 45°, $.69976 \pm 0.00002$

Hence 1 liter weighs 1.42906 ± 0.00004 gramme.

Dividing this by the weight found for hydrogen, 0.089947 ± 0.000012 we have for the ratio H : O,

$$15.8878 \pm 0.0022$$

The density ratios, H : O, now combine as follows:

Dumas and Boussingault, corrected	15.9015 ± 0.031
Regnault, corrcted	$15.9105 \pm .0044$
Rayleigh, 1888	$15.884 \pm .0048$
Rayleigh, 1892	$15.882 \pm .0023$
Cooke	$15.890 \pm .0067$
Leduc	$15.906 \pm .0154$
Morley, including all the data	$15.8955 \pm .0005$
Thomsen	$15.8878 \pm .0022$
General mean	$15.8948 \pm .00048$

If we reject all of Morley's data for the density of hydrogen except his third, fourth, and fifth series, the mean becomes

$$15.8991 \pm 0.00048$$

In either case Morley's data vastly outweigh all others.

If oxygen and hydrogen were perfect gases, uniting by volumes exactly in the ratio of 1 to 2, then their relative densities would also indicate their relative molecular weights. But, in fact, the two gases vary from Boyle's law in opposite directions, and the true composition of water by volume diverges from the theoretical ratio to a measurable extent. Hence, in order to deduce the atomic weight of hydrogen from its density, or that of oxygen, if the hydrogen scale is

preferred, a small correction must be applied which depends upon the amount of the divergence. Until modern times our knowledge of the volumetric composition of water rested entirely upon the determinations made by Humboldt and Gay Lussac [1] early in the last century, which gave a ratio between H and O of a little less than 2 : 1, but their data need no farther consideration here.

In 1887 Scott [2] published the first series of experiments, 21 in number, finding as the most probable result a value for the ratio of 1.994 : 1. In March, 1888,[3] he gave four more determinations, ranging from 1.9962 to 1.998 : 1; and later in the same year [4] another four, with values from 1.995 to 2.001. In 1893,[5] however, by the use of improved apparatus, he was able to show that his previous work was vitiated by errors, and to give a series of measurements of far greater value. Of these, 12 were especially good, being made with hydrogen from palladium hydride, and with oxygen from silver oxide. In mean the value found is 2.00245 ± 0.00007, with a range from 2.0017 to 2.0030.

In 1891 an elaborate paper by Morley [6] appeared, in which 20 concordant determinations of the volumetric ratio gave a mean value of 2.00023 ± 0.000015. These measurements were made in eudiometer tubes, and were afterwards practically discarded by the author. In his later and larger paper,[7] however, he redetermined the ratio from the density of the mixed electrolytic gases, and found it to be, after applying all corrections, 2.00274. The probable error, roughly estimated, is 0.00005. Morley also reduces Scott's determinations, which were made at the temperature of the laboratory, to 0°, when the value becomes 2.00285. Leduc's [8] single determination, based upon the density of the mixed gases obtained by the electrolysis of water, gave 2.0037; but Morley shows that some corrections were neglected. This determination, therefore, may be left out of account.

There is also a corroborative measurement by Rayleigh,[9] who assigns to the ratio the value 2.0026. This agrees well with the figures given by Scott and Morley. Rayleigh also gives measurements of gaseous densities at very low pressures, and obtains molecular ratios differing considerably from those ordinarily found. At atmospheric pressure, for example, H = 1.0075; and at very low pressures its atomic weight becomes 1.0088.

In 1917 an elaborate redetermination of this volume ratio, by Burt and Edgar,[10] appeared. Five series of determinations were made, with varying conditions, and with all known precautions against error. Omitting details, the mean values for these series are as follows:

Series 1, twelve measurements	2.00294 ± 0.00002
Series 2, ten measurements	2.00292 ± 0.000014
Series 3, ten measurements	2.00292 ± 0.00001
Series 4, ten measurements	2.00301 ± 0.00002
Series 5, twelve measurements	2.00287 ± 0.00001
General mean	2.00294 ± 0.0000058

This mean is subject to two small corrections, which reduce it to 2.00288, ± 0.0000058. For comparison this may be combined with the previous determinations, neglecting those of Leduc and Rayleigh, thus:

Scott, corrected	2.00285 ± 0.00007
Morley	2.00274 ± 0.00005
Burt and Edgar	2.00288 ± 0.0000058
General mean	2.00287 ± 0.0000057

[1] Journ. de Phys., 60, 129.
[2] Proc. Roy. Soc., 42, 396.
[3] Nature, 37, 439.
[4] British Assoc. Report, 1888, 631.
[5] Proc. Roy. Soc., 53, 130. In full in Philosophical Transactions, 184, 543, 1893.
[6] Amer. Journ., Sci. (3), 46, 230 and 276.
[7] Already cited with reference to syntheses of water.
[8] Compt. Rend., 175, 311. 1892. In a later, more complete menoir, Ann. Chim. Phys. (7), 15, 49, Ldeuc gives the figures 2.0034. He also criticizes Morley's deductions.
[9] Proc. Rou. Soc., 73, 153. 1904.
[10] Phil. Trans., series A, vol. 216, pp. 393–427.

This is practically Burt and Edgar's value alone. The others vanish. Combining their value for the volume ratio with Morley's values for the densities of oxygen and hydrogen, Burt and Edgar conclude that

$$H = 1.00772.$$

Now, including all the data so far considered, we have as a mean value for the density ratios:

$$(A)\quad H:O::1:15.8948 \pm .00048,$$

or, omitting Morley's rejected series for hydrogen,

$$(B)\quad H:O::1:15.8991 \pm .00048.$$

Correcting these by the volume ratio, $2.00287 \pm .0000057$, the final result for the atomic weight of oxygen, in terms of the hydrogen unit, and as computed from the gaseous densities becomes—

From A	O=15.8720 ±.00048
From B	O=15.8763 ±.00048

Combining these figures with the values deduced from the syntheses of water, rejecting nothing, we have—

By syntheses of water	O=15.8779 ±.00016
By gaseous densities	O=15.8720 ±.00048
General mean	O=15.8773 ±.00015
Hence, on the oxygen scale	H=1.00773 ±.00001

If we reject the seven highest values under the first heading, and omit Morley's defective hydrogen series under the second, we get—

By syntheses of water	O=15.8760, ±.00017, or H=1.00781 ±.00001
By gaseous densities	O=15.8763, ±.00048, or H=1.00779 ±.00003
General mean	O=15.8761, ±.00016, or H=1.00780 ±.00001

The two component values of the last mean are practically identical, and fix the atomic weight of hydrogen as very close to

$$H = 1.0078 \pm .00001.$$

The actual uncertainty of this value, however, is greater than the so-called "probable error." The latter, it must be borne in mind, is a mathematical expression which should not be used in a colloquial sense. For computations of this kind the probable error is essentially a coefficient of concordance, which merely indicates the relative value or weight assignable to a given series of observations in comparison or combination with others.

In the foregoing discussion both chemical and physical data have been taken into account. In recent years, however, much has been done on the purely physical side; and the molecular weights of gases have been deduced from physical evidence alone. In these calculations the weight of a normal liter of oxygen is a fundamental standard of reference, and a number of investigators have sought to determine it accurately. Jaquerod and Pintza,[1] for example, give as the mean of five determinations, the value 1.4292 grams, but without the individual figures. Jaquerod and Tourpaian [2] also, but without details, find it to be 1.4290 grammes.

Guye,[3] from data given in different forms by other investigators, has computed the following values for this constant:

From data by Rayleigh	1.42905
From data by Leduc	1.42876
From data by Gray	1.42896

The arithmetical (unweighted) mean of these five values is 1.42899 grammes.

[1] Compt. Rend., 139, 129. [2] Arch. Sci. Phys. Nat., (4) 31, 20. [3] Journ. Chim. Phys., 5, 203. 1907.

The most recent determinations of the constant now under consideration are those by Scheuer [1] and Germann.[2] Scheuer made 24 determinations, which gave in mean as the crude weight of a liter of oxygen the value 1.42954 ± .000016 grammes. Corrected for latitude and elevation the weight of the normal liter becomes 1.42906 grammes. By Germann there are 15 determinations, in mean 1.42924 ± .000058 grammes crude, or 1.42906 normal. Continuing these values with the preferred figure given by Morley and the determination by Thomsen, we have—

Morley, preferred	1.42900 ± .000028
Thomsen	1.42906 ± .00004
Scheuer	1.42906 ± .000016
Germann	1.42906 ± .000058
General mean	1.42905 ± .000013

This value, combined with Morley's figure for the weight of a liter of hydrogen, and Burt and Edgar's volume ratio gives

$$H = 1.00768$$

as compared with the 1.00780 of my general combination, which includes the purely chemical determinations.

Several recent discussions of the physical data relative to the atomic weight of hydrogen are worth citing here. Jaquerod and Scheuer [3] reduced the gaseous densities by measuring the compressibilities of hydrogen and oxygen, and found H = 1.0078. Grinnell Jones,[4] in a very careful reduction of the density ratios by several methods found H = 1.00775. Guye,[5] from the established densities of the two gases, with various corrections and a discussion of sources of error, concludes that the true value lies between 1.00767 and 1.00773; or, in mean, that H = 1.00770. Hinrichs,[6] in a calculation which was partly theoretical, decided that H = 1.0081. These various values compare as follows:

Clarke	H=1.0078
Jaquerod and Scheuer	H=1.0078
Jones	H=1.00775
Guye	H=1.0077
Burt and Edgar	H=1.00772
Hinrichs	H=1.0081

The first five of these values are fairly concordant, and justify the belief that the atomic weight of hydrogen is fixed with an uncertainty not greater than 1 part in 10,000. My own value, which involves both chemical and physical determinations, will be used throughout this work. For reductions of data relative to gases other than oxygen and hydrogen, the Morley value for hydrogen, and the normal figure for oxygen, 1.42905 grammes at 0°, 760 mm. pressure, latitude 45 N., and sea level will be employed.[7]

THE NITROGEN-OXYGEN RATIO.

The direct ratio between nitrogen and oxygen has been determined by analyses of the oxides of nitrogen and by measurements of gaseous densities. The different methods may be considered in regular order.

The exact analysis of nitrous oxide, with reference to the atomic weight of nitrogen, was effected by Guye and Bogdan.[8] The gas itself was condensed in carefully purified charcoal, and so weighed; it was then passed slowly through a tube containing a spiral of iron wire, which

[1] Anzeiger Wien Akad., 50, 378.
[2] Journ. Chim. Phys., 12, 66. Journ. Phys. Chem., 19, 437. Germann gives an exhaustive summary of the earlier investigations.
[3] Compt. Rend., 140, 1384.
[4] Journ. Amer. Chem. Soc., 32, 513.
[5] Journ. Chim. Phys., 15, 208.
[6] Rév. Gén. Chim., 13, 361.
[7] Two additional values for the weight of a liter of oxygen at 0° and 760 mm., but uncorrected for latitude and elevation, are worth putting on record here. By Guye Kovacs and Wourtzel at Geneva (Journ. Chim. Phys., 10, 332), 1.42819 grammes, the mean of 15 determinations. By Bruylants and Bytebier at Louvain (Bull. Acad. Belge, 1912, 856) 1.4295 grammes, the mean of 10 determinations.
[8] Compt. Rend., 138, 1494. 1904. Journ. Chim. Phys., 3, 537. 1905.

was heated to redness by an electric current. The iron was oxidized, and its gain in weight gave the amount of oxygen in the N_2O. The results obtained were as follows:

Wt. N_2O.	*Wt. O.*	*At. Wt. N.*
1.1670	.4242	14.0085
.9498	.3453	14.0052
.8652	.3145	14.0083
1.2247	.4455	13.9924
1.4202	.5159	14.0229
		Mean, 14.0075±.0033

For the complete gravimetric analysis of nitric oxide we have the elaborate data furnished by R. W. Gray.[1] The gas was weighed, and then reduced by electric heating over finely divided metallic nickel. The gain in weight of the nickel represented the amount of oxygen absorbed. In some of the experiments the liberated nitrogen was condensed, at the temperature of liquid air, in cocoa-nut charcoal, and its weight also was determined. Two series of determinations were made, on nickel from different sources, but for present purposes these may be treated as one. For three of the measurements corrections are given for the nitrogen occluded by the mixed nickel and nickel oxide, which corrections I have applied in the following table of Gray's results:

Wt. NO.	*Wt. O.*	*Wt. N.*
.31384	.16729	.....
.64304	.34300	.30010
.50672	.27025	.....
.54829	.29221	.....
.61862	.32981	.28885
.62622	.33401	.29234
.62128	.33111	.....
.54469	.29029	.25432
.52001	.27715	.24270
.62103	.33103	.28998

From these weights the subjoined values for N are derived.

NO:O_2.	*N_2:O_2.*	*NO:N_2.*
14.0164	.....	.....
13.9960	13.9988	13.9996
14.0001	.....	.....
14.0217	.....	.....
14.0110	14.0129	14.0146
13.9997	14.0039	14.0094
14.0217	.....	.....
14.0218	14.0174	14.0136
14.0204	14.0112	14.0031
14.0169	14.0159	14.0151
Mean, 14.0126±.0022	14.0100±.0020	14.0092±.0018

The general mean of the three series is N = 14,0104 ± .0011

The analyses of nitrogen peroxide, by Guye and Drouginine,[2] are similar in character to those of nitrous oxide by Guye and Bogdan. A spiral of iron wire was electrically heated in a bulb containing a known weight of the peroxide, and the increased weight of the spiral gave the amount of oxygen released by the complete decomposition of the initial compound. For the elaborate details relative to manipulation the original memoir should be consulted. The weights, in grams, are as follows:

Wt. N_2O_4.	*Wt. $2O_2$.*	*Wt. N_2.*	*At. Wt. N.*
0.8856	0.6160	0.2696	14.005
1.8494	1.2860	0.5634	14.019
2.1281	1.4801	0.6480	14.010
1.7191	1.1957	0.5234	14.008
0.9951	0.6921	0.3030	14.010
1.5324	1.0658	0.4666	14.009
1.2425	0.8642	0.3783	14.008
			Mean, 14.0099±.0011

[1] Journ. Chem. Soc., 87, 1601. 1905.

[2] Journ. Chim. Phys., 8, 473, 1910.

An entirely different process for determining the atomic weight of nitrogen was adopted by Wourtzel,[1] who oxidized nitric oxide, NO to the peroxide, N_2O_4. The nitric oxide was first dissolved in liquefied NO_2, forming nitrous anhydride, N_2O_3. The latter was then oxidized by a stream of dry oxygen. All the operations were effected at very low temperatures. The weights were as follows:

Wt. NO.	*Wt. O_2 absorbed.*	*At. Wt. N.*
1.3653	0.72805	14.005
1.76655	0.9419	14.008
1.5983	0.85225	14.006
1.9562	1.04305	14.007
2.1854	1.1652	14.008
		Mean, 14.0068±.0004

The five series of determinations of the atomic weight of nitrogen, by Scheuer,[2] appear to have been published only in abstract, without the details needed for their critical discussion. Other work by Scheuer, however, has been of such good character, that these determinations may be accepted as trustworthy. Three of the series were synthetic, the other two give analyses of nitrogen oxides. The data are as follows:

Series 1.—Syntheses of N_2O_4 from NO and O_2.

Wt. NO.	*Wt. $_2NO_4$.*	*At. Wt. N.*
1.22627	1.88011	14.0078
1.23426	1.89086	14.0073
1.22527	1.87861	14.0063
1.22906	1.88437	14.0087
		Mean, 14.0075±.0005

Series 2.—Syntheses of N_2O_3 from NO and O_2.

Wt. NO.	*Wt. N_2O_3*	*At. Wt. N.*
2.45259	3.10643	14.0085
2.46280	3.11940	14.0087
2.45063	3.10397	14.0074
2.45809	3.11340	14.0083
		Mean, 14.0077±.0004

Series 3.—Syntheses of N_2O_4 from N_2O_3 and O_2.

Wt. N_2O_3	*Wt. N_2O_4*	*At. Wt. N.*
1.20468	1.45825	14.0070
1.53106	1.85331	14.0092
1.64258	1.98829	14.0083
3.11340	3.76873	14.0071
		Mean, 14.0079±.0005

Series 4.—Analyses of N_2O_4.

Wt. N_2O_4	*Wt. O_2*	*Wt. N_2*	*At. Wt. N.*
0.92456	0.64304	0.28152	14.0095
.99827	.69434	.30393	14.0072
.95147	.66177	.28970	14.0085
.89762	.62341	.27331	14.0090
			Mean, 14.0085±.0005

Series 5.—Analyses of N_2O_3.

Wt. N_2O_3	*Wt. O_2*	*Wt. N_2*	*At. Wt. N.*
0.97434	0.61523	0.35911	14.0083
.92776	.58582	.34194	14.0086
.96347	.62733	.36614	14.0075
.97145	.61339	.35806	14.0097
.94570	.59714	.34856	14.0092
			Mean, 14.0086±.0004.

[1] Compt. Rend., 154, 115, 1912.

[2] Anzeiger Wien Akad., 49, 38, 1912.

The atomic weights and probable errors are all as given by Scheuer. They have not been recalculated here.

We now have nine series of determinations, which combine as follows:

Guye and Bogdan	N=14.0075±.0033
Gray	N=14.0104±.0011
Guye and Drouginine	N=14.0099±.0011
Wourtzel	N=14.0068±.0004
Scheuer, Series 1	N=14.0075±.0005
Scheuer, Series 2	N=14.0077±.0004
Scheuer, Series 3	N=14.0079±.0005
Scheuer, Series 4	N=14.0085±.0005
Scheuer, Series 5	N=14.0086±.0004
General mean	N=14.0079±.00018

The accurate calculation of molecular and atomic weights from gaseous densities is really an affair of very recent times. The gases, as measured, show divergencies from Avogadro's law, and the crude density ratios therefore require correction, as we have already seen in reference to the atomic weight of hydrogen. It seems best, however, to assemble the actual measurements first and to apply the corrections to the entire mass of data afterwards.

For nitrogen there are abundant measurements made upon the element itself, and also good data for nitrous oxide, nitric oxide, and ammonia,

The earlier determinations of the density of nitrogen were all made upon nitrogen derived form the atmosphere. But the supposed nitrogen contained, as we now know, the heavier argon, and the value obtained was therefore incorrect. It is, however, worth while to examine the data, and to see whether a correction for argon may not be advantageously made. The very early work of Biot and Arago, Thomson, Dulong and Berzelius, Lavoisier, and others can be neglected, and, as in the case of oxygen, we need consider only the results obtained by Dumas and Boussingault, Regnault, and several more recent investigators.

Taking air as unity, Dumas and Boussingault[1] found the density of atmospheric nitrogen to be—

.970
.972
.974

Mean, .972±.00078

For oxygen, as was seen in our discussion of the O:H ratio, the same investigators found a mean of 1.10567, ±.00006. The ratio between this and the nitrogen figure is 16:14.0657, ±.0113.

By Regnault[2] much closer work was done. He found the density of atmospheric nitrogen to be as follows:

.97148	.97155
.97148	.97108
.97154	.97108

Mean, .97137±.000062

For oxygen, Regnault's mean value is 1.105633, ±.000008. Hence, combining as before, N=14.057, ±.0009.

Both of the preceding values are affected by a correction for the difference in volume between the weighing globes when full and when empty. This correction, in the case of Regnault's data, was measured by Crafts,[3] who gives 1.10562 for the density of oxygen, and 0.97138 for that of nitrogen. The changes are so small that the ratio remains practically unaltered. The correction in this particular instance is negligible.

Von Jolly,[4] working with electrolytic oxygen and with nitrogen prepared by passing air over hot copper, compared the weights of equal volumes of the two gases, with results as follows:

[1] Compt. Rend., 12, 1005. 1841.
[2] Compt. Rend., 20, 975. 1845.
[3] Compt. Rend., 106, 1664.
[4] Annalen der Physik. (2), 6, 529. 1879.

Oxygen.	*Nitrogen.*
1.442470	1.269609
1.442579	1.269389
1.442489	1.269307
1.442570	1.269449
1.442571	1.269515
1.442562	1.269443
1.442478	1.269478
Mean, 1.442545±.000013	Mean, 1.269455±.000024

The ratio, when O = 16, is N = 14.0802 ± .0003. Corrected by Rayleigh, the ratio between the weights becomes 14.0805.

The next determination in order of time is Leduc's.[1] He made nine measurements of the density of atmospheric nitrogen, giving a mean of .97203, with extremes of .9719 and .9721; but he neglected to cite the intermediate values. Taking the three figures given as representative, and assuming a fair distribution of the other values between the indicated limits, the probable eroor of the mean is not far from 0.00002. For oxygen he found 1.10514 ± .000032. The ratio between the two densities is 16 : 14.0729 ± .0005.

Lord Rayleigh,[2] who prepared nitrogen from the atmosphere by several methods, and weighed it in a standard globe in direct comparison with oxygen, obtained the following weights:

Oxygen.	*Nitrogen.*
2.6272	2.31035
2.6271	2.31026
2.6269	2.31024
2.6269	2.31012
2.6271	2.31027
Mean, 2.62704±.00004	2.31025±.000025

In a later paper [3] Rayleigh gives the following additional weights for atmospheric nitrogen, which are directly comparable with the foregoing series:

2.31017	2.31001	2.31028
2.30986	2.31024	2.31163
2.31010	2.31010	2.30956

Including these figures with those of the first series, the mean of all becomes 2.31023 ± .00008. Correcting these data for the compression of the empty globes, the mean weights become, for oxygen, 2.6276 ± .00004, and for nitrogen, 2.31079 ± .00008. The ratio between them is 16 : 14.0704 ± .0005.

The combination of these determinations is as follows:

Dumas and Boussingault	14.0657±.0113
Regnault	14.0570±.0009
Von Jolly	14.0805±.0003
Leduc	14.0729±.0005
Rayleigh	14.0704±.0005
General mean	14.0758±.00022

Now, to correct this mean for the argon contained in the nitrogen. Good measurements have shown that normal air contains, by volume, 0.937 per cent of argon, and 78.122 of nitrogen. The density of argon, referred to the oxygen standard, is 19.940. Applying these values, the final figure for nitrogen, derived from air, becomes 14.0052 ± .00022, a result which is in harmony with others to be considered presently.

In Rayleigh's investigation of the density of nitrogen it was found that nitrogen from chemical sources was lighter than that extracted from the atmosphere. This led to the dis-

[1] Compt. Rend., 113, 186. 1891. [2] Proc. Roy. Soc., 53, 134. 1893. [3] Proc. Roy. Soc., 55, 340. 1894.

covery of argon, to which reference has already been made. In two of his memoirs [1] Rayleigh has given determinations of the density of "chemical nitrogen" obtained from nitrous oxide, nitric oxide, ammonium nitrite, urea, and magnesium nitride, and the gas from all these sources is precisely the same. His weights, given now as one series, and representing the same volume as those previously cited, are as follows:

2. 30143 from nitric oxide
2. 29890 from nitric oxide
2. 29816 from nitric oxide
2. 30182 from nitric oxide
2. 29869 from nitrous oxide
2. 29940 from nitrous oxide
2. 30074 from nitrous oxide
2. 30054 from nitrous oxide
2. 29849 from ammonium nitrite
2. 29889 from ammonium nitrite
2. 29870 from ammonium nitrite
2. 29850 from urea
2. 29918 from magnesium nitride
Mean, 2. 29949 ± .00024

Corrected for the compression of the empty globe, this mean becomes 2.30005. The weight of an equal volume of oxygen was found to be 2.62760 ± .00004. Hence the ratio is 16 : 14.0055 ± .0015.

Two determinations of density for "chemical nitrogen" are given by Leduc.[2] In mean, the value found, referred to air as unity, is 0.96717 ± .00008. This, combined with the figure already cited for oxygen gives, as the value for the ratio under discussion, 16 : 14.0025 ± .0012. There are also two determinations by Gray,[3] whose comparative weights at 0° and 760 mm., are as follows:

Nitrogen.	*Oxygen.*
.32286	.36889
.32275	.36879
Mean, .322805 ± .00004	Mean, .36884 ± .00003

Hence the ratio 16 : 14.0030 ± .0021.

It is evident that the data given by Leduc and Gray are overvalued in comparison with Rayleigh's much larger series of determinations. The general mean, however, as shown in the following combination, can not be far from the truth:

Rayleigh	14. 0055 ± .0015
Leduc	14. 0025 ± .0012
Gray	14. 0030 ± .0021
General mean	14. 0036 ± .00085

Hence the normal liter of nitrogen weighs 1.25066 grams.

For the density of nitrous oxide there are several series of measurements. Leduc [4] gives three figures, as follows, referred to air as unity:

1. 5304
1. 5298
1. 5301
Mean, 1. 5301 ± .00012

Combined with Leduc's value for oxygen, this gives the density ratio

$$O_2 : N_2O : : 32 : 44.3050 \pm .0037.$$

By Rayleigh there are two series of determinations,[5] made at different times. In the earlier series the gas was possibly contaminated by traces of nitrogen, in the second series the nitrous

[1] Proc. Roy. Soc., 55, 340, 1894, and 57, 266, 1895.
[2] Ann. Chim. Phys. (7), 15, 33. 1898.
[3] Journ. Chem. Soc., 87, 1601. 1905.
[4] Ann. Chim. Phys. (7), 15, 35. 1898.
[5] Proc. Roy. Soc., 62, 204, 1897, and 74, 181, 1904.

oxide was purified by condensation at the temperature of liquid air. The weights of nitrous oxide filling his standard globe are subjoined.

1897 series.	*1904 series.*
3.6359	3.6368
3.6354	3.6360
3.6364	3.6362
3.6358	3.6363
3.6360	3.6367
	3.6366
Mean, 3.6359	3.6354
	Mean, 3.6363

These are so nearly together that I venture to treat them as one series, in mean $3.6361 \pm .000093$. The weight of the same volume of oxygen was $2.6276 \pm .00004$. The value of the ratio, therefore, is $32 : 44.2819 \pm .0037$.

The measurements by Guye and Pintza [1] are stated so as to show the weight of a normal liter of nitrous oxide. The figures are, in grammes—

	1.97762
	1.97707
	1.97760
Mean,	$1.97743 \pm .00015$

The weight of a normal liter of oxygen is $1.42905 \pm .000013$. Combining this with Guye and Pintza's figure the ratio becomes $32 : 44.2796 \pm .0040$.

The three independent values for the density ratio O_2:N_2O, combine as follows:

Leduc	$44.3050 \pm .0037$
Rayleigh	$44.2819 \pm .0037$
Guye and Pintza	$44.2796 \pm .0040$
General mean	$44.2889 \pm .0023$

This mean corresponds to a normal liter-weight for nitrous oxide of 1.97785 grammes.

It is convenient at this point to consider the volumetric analysis of nitrous oxide made by Jacquerod and Bogdan.[2] A measured volume of the gas was decomposed by an electrically heated spiral of iron wire, and the volume of the residual nitrogen was measured afterwards. Then, with the known densities of the two gases, the ratio between them was easily calculable. Reduced to uniform conditions, one liter of nitrous oxide gave the following volumes of nitrogen:

	1.00737
	1.00698
	1.00714
	1.00718
Mean,	$1.00717 \pm .000054$

To this value, however, a correction is yet to be applied, namely, for the increase in volume of the iron wire consequent upon oxidation. This demands a deduction of 0.00030, which reduces the mean to 1.00687. That is, one liter of nitrous oxide, decomposed, yields 1.00687 liters of nitrogen. Hence the following calculation:

1 liter N_2O weighs	1.97785	grammes.[3]
1.00687 N_2 weighs	$1.25066 \times 1.00687 = 1.25925$	"
Oxygen in N_2O,	0.71860	"

[1] Compt. Rend., 139, 677. 1904. Corrected in C. R., 141, 51. 1905. The corrected figures are used here.

[2] Journ. Chim. Phys., 3, 562. 1905.

[3] Jaquerod and Bogdan assume, for the liter-weights of N_2 and N_2O, 1.25045 and 1.97772, respectively. I here use the weights previously computed in this chapter. Jaquerod and Bogdan find N=14.015.

From these data, $O : N_2 : : 0.7186 : 1.25925 = 28.0388$, and $N = 14.0189 \pm .0030$. The probable error is computed from the figures already given relative to the densities of the gases.

For the density of nitric oxide there are three modern investigations. First, by Gray;[1] second, by Guye and Davila,[2] and third, by Scheuer.[3] Gray gives two series of weights, in which nitric oxide is directly compared with an equal volume of oxygen. Two supplementary determinations are cited as additions to series 2.

Oxygen.	*NO 1.*	*NO 2.*
.38230	.35845	.35851
.38229	.35852	.35848
.38227	.35851	.35852
.38225	.35849	.35850
.38226	.35859	.35848
.38230	.35856	.35855
Mean, .38228 ± .0000058	Mean of all, .35851 ± .0000076	

From these weights the crude density ratio is

$$O_2 : NO : : 32 : 30.0102 \pm .0007.$$

Guye and Davila prepared their nitric oxide by three distinct methods, and obtained the following figures for the normal liter-weight.

I.	*II.*	*III.*
1.3406	1.3403	1.3399
1.3402	1.3398	1.3403
1.3401	1.3400	
1.3407	1.3408	
1.3398	1.3402	
1.3402	1.3402	

The mean of the 14 determinations, taken as one series, is $1.3402 \pm .000056$. With the accepted weight of the normal liter of oxygen, $1.42905 \pm .000013$, the density ratio becomes—

$$O_2 : NO : : 32 : 30.0104 \pm .0011.$$

Scheuer's figures for the weight of a liter of nitric oxide are as follows:

1.34047	1.34053	1.34064	1.34059
1.34073	1.34058	1.34039	1.34076
1.34067	1.34060	1.34066	1.34062
1.34049	1.34062	1.34068	1.34042

Mean, $1.34059 \pm .000018$

Corrected (Scheuer) the weight of the normal liter is 1: 34014 grammes, and—

$$O^2 : NO : : 32 : 30.0091 \pm .0005.$$

The three series of determinations combine thus—

Gray	$NO = 30.0102 \pm .0007$
Guye and Davila	$NO = 30.0104 \pm .0011$
Scheuer	$NO = 30.0091 \pm .0005$
General mean	$NO = 30.0095 \pm .00038$

This corresponds to a normal liter-weight of $1.34016 \pm .000017$.

The density of gaseous ammonia, according to Leduc,[4] is 0.5971, referred to air as unity. But this figure represents only a single determination, with material of doubtful purity, and need not be considered further. Guye and Pintza,[5] with carefully purified ammonia, made five determinations of density, which gave the subjoined results for the weight of the normal liter:

.77080	.77099
.77069	.77076
.77073	

Mean, $.77079 \pm .000035$

[1] Journ. Chem. Soc., 87, 1601. 1905.
[2] Compt. Rend., 141, 826. 1905.
[3] Anzeiger Wien Akad., 50, 378. 1913.
[4] Ann. Chim. Phys. (7), 15, 39. 1898.
[5] Compt. Rend., 141, 51. 1905.

Perman and Davies [1] made three series of determinations, by two methods; but the first series, with commercial ammonia, is to be rejected. The other series gave the following figures for the weight of one liter of the gas:

I.	*II.*
.7709	.77094
.7711	.77094
.7712	.77090
.7713	.77088
.7711	.77091
.7713	
Mean, .77115	Mean, .77094

Corrected, by reduction to latitude 45° and sea level these two series taken as one, give in value $0.770855 \pm .000034$ grams as the weight of a normal liter of ammonia.

There is also a later series of determinations by Scheuer,[2] as follows:

.77098	.77121
.79124	.77088
.77083	.77115
.77102	.77091

Mean, $0.77103 \pm .000056$.

Corrected (Scheuer), this gives as the weight of the normal liter,

$$0.77077 \pm .000056 \text{ grams.}$$

The three series combine thus:

Guye and Pintza.....	.77079 ±.000035
Perman and Davies.....	.770855±.000034
Scheuer.....	.77077 ±.000056
General mean.....	.77081 ±.000022

Hence, with the accepted value for the normal liter of oxygen, $1.42905 \pm .00013$, the crude density ratio is—

$$O_2 : NH_3 :: 32 : 17.2605 \pm .00043.$$

The law of Avogadro, that equal volumes of gases contain equal numbers of molecules, is rigorously true only for ideally perfect gases. For gases as they actually occur it is approximately true, but with varying degrees of divergence. The approximation is close for the so-called permanent gases, while those which are easily liquefiable conform less nearly to the law. In order, therefore, to compute molecular weights from observed gaseous densities, it is necessary to apply corrections to the experimental data, or else to employ methods of determinations of great manipulative difficulty. By measuring densities at very low pressures, quite close approximations to the truth may be obtained, and observations at high temperatures are also nearly valid. For example, Rayleigh [3] from gaseous densities at very small pressures, obtained the following value for nitrogen, as compared with the standard, oxygen:

$$N_2 = 28.018, \text{ and } N = 14.009.$$

On the other hand, by measuring the density of nitrogen at 1067.4°, Jaquerod and Perrot [4] found—

$$N_2 = 28.0155, \text{ and } N = 14.0077.$$

These values are probably not far from the truth, and are obviously well in accord. At low pressures and at high temperatures gases are more nearly in agreement with Avogadro's law than they are under ordinary conditions.

In the case of the oxygen-hydrogen ratio, the density corrections were determined by actual measurement of the volumes in which the two gases combined, a method which is not always

[1] Proc. Roy. Soc., 78A, 28. 1906. Perman and Davies give still other density determinations for different temperatures and pressures.
[2] Anzeiger Wien Akad., 49, 38. 1912.
[3] Proc. Roy. Soc., 73. 153. 1904.;
[4] Compt. Rend., 140, 1542. 1905.

applicable, or at least not conveniently so. It is easier to compute the corrections from physical data, and for this purpose various methods have been proposed.[1]

The following formulæ, based upon the celebrated gas equation of Van der Waals, are according to Guye,[2] available for the reduction of gaseous densities to true molecular weights:

$$\text{I.} \qquad M = \frac{(R \times mT)L}{(1+a)\ (1-b)} \qquad\qquad \text{II.} \qquad M = \frac{RL}{(1+a_0)\ (1-b_0)}$$

Equation I applies to the permanent gases, that is, to those which are liquefiable only below 0°. Equation II applies to the easily liquefiable gases. R is the gas constant, and according to Berthelot [3] its value is 22.412. The constant m, of equation I, is given by Guye the value 0.0000623. T represents the critical temperature, on the absolute scale; L is the weight of one liter of gas at 0°, 760 mm., sea level, and latitude 45°; and M is the molecular weight. The symbols a and b are the constants of the Van der Waals equation, which vary for different gases, and in II are brought to the standard temperature and pressure.

In any given case the use of these formulæ requires a knowledge of the constants a and b. These can be deduced from the compressibilities and coefficients of expansion of a gas, or from the critical constants. The latter method is the one adopted by Guye, and with one exception it will be followed here. Guye gives the required data in form ready for use,[4] and they yield results which appear to be trustworthy. Applied to the densities given in the preceding pages they give the following reductions:

Nitrogen, chemical.—L = 1.25066. T = 127.5°. $(1+a)\ (1-b = 1.00100$. Hence N = 14.0058 ± .00085. From the figures given for atmospheric nitrogen, N = 14.0074 ± .00022. The weighted mean is N = 14.0073 ± .0002.

Nitrous oxide.—L = 1.97785. $(1+a_0)\ (1-b_0) = 1.00733$. Hence $N_2O = 44.0060 \pm .0023$. The crude density ratio gives 44.2889 ± .0023, showing that the correction is large.

Nitric oxide.—L = 1.34016. T = 179.5°. $a = 0.00257$. $b = 0.00115$. Hence NO = 30.0081 ± .00038.

Ammonia.—The crude density ratio gave $NH_3 = 17.2605 \pm .00043$. This has been reduced by means of compressibility data. Perman and Davies, who measured the compressibility, give the multiplying factor 0.9867, whence $NH_3 = 17.0309$. Jaquerod and Scheuer,[5] by a different formula, and using only the density determinations of Guye and Davila, find $NH_3 = 17.0148$. If H = 1.0078, N = 14.0075, Perman and Davies' method, or 13.9914 by Jaquerod and Scheuer. The first value is apparently the best and will be adopted here.

There are now five independent values for N, as follows:

From analyses and syntheses	N = 14.0079 ± .00018
From density of N_2	N = 14.0073 ± .00020
From density of N_2O	N = 14.0030 ± .00105
From density of NO	N = 14.0081 ± .00038
From density of NH_3	N = 14.0075 ± .00043
General mean	N = 14.0076 ± .00012

From compressibility data Rayleigh [6] found from N_2, N = 14.008, and from N_2O, N = 13.998. His low pressure value, as previously cited, was N = 14.009, and Jaquerod and Perrot, at high temperatures, found N = 14.0077. To include these values in the general mean would change the final result inappreciably, if at all, and they may therefore be disregarded. They have, however, confirmatory significance.

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[1] See D. Berthelot, Journ. Physique (3), 8, 263. 1899. Leduc, Ann. Chim. Phys. (7), 15, 1. 1898. Guye and Friederich, Arch. Sci. Phys. Nat. (4), 9, 505, and 13, 559. Guye, Journ. Chim. Phys., 3, 321, and 5, 203, also Compt. rend., 138, 1213, and 140, 241. There is a copious literature upon this subject.

[2] Journ. Chim. Phys., 3, 321. 1905.

[3] Zeitsch. Elektrochem., 1904, 621. In Journ. Physique (3), 8, 527, Berthelot gives values of a and b for several gases.

[4] When Guye gives two or more figures for $(1+a)\ (1-b)$ I take the average.

[5] Compt. Rend., 140, 1384. 1905. From NO Jaquerod and Scheuer found N = 14.005.
Proc. Roy. Soc., 74, 446. 1904

Some of the determinations utilized in the foregoing combination are evidently overvalued, especially the figure derived from atmospheric nitrogen. The "probable error" here assigned to N, simply indicates the weight which it should receive in calculating other atomic ratios.[1]

As a check upon the other determinations of the atomic weight of nitrogen, Guye and Pintza[2] have determined the composition of ammonia by volume. The gas was decomposed by a spiral of platinum wire heated to redness, and from the density of the mixed gases, $N_2 + 3H_2$, compared with the known densities of nitrogen and hydrogen, the required datum was calculated. For the weight, in grammes, of a normal liter of the gaseous mixture, the following figures were obtained:

0.38044
0.38055
0.38046

Mean, $0.38048 \pm .000024$

Corrected for traces of SO_2 and SO_3, this becomes 0.37989 If the weights of the normal liters of N_2 and H_2 are 1.2507 and 0.08987, respectively, the two gases in ammonia are combined in the ratio 1 : 3.00172. Applying this datum to the densities of nitrogen and hydrogen, and assuming $H = 1.0078$, $N = 14.017$, with a probable error, not exactly calculable, greater than $\pm .0017$. To combine this figure with the value already found would change the latter inappreciably. Indeed, Guye and Pintza regard their determinations as inferior to those made by other methods, and publish their results only as a confirmation of the low value for N, as compared with the value 14.04 which had been in general acceptance form any years. The aberrant value derived from the volumetric analysis of nitrous oxide can also be neglected.

THE CARBON-OXYGEN RATIO.

The ratio between carbon and oxygen, or in other words, the atomic weight of carbon, has been directly determined by several methods. It has also been indirectly computed from analyses of silver salts, such as the acetate; but that group of ratios will be considered under another heading. The early attempts to estimate it from analyses of hydrocarbons, have now only historic value, and can be omitted from the present discussion. The direct measurements of the ratio represent three distinct processes:

First, by the combustion of carbon itself.

Second, by the combustion of carbon monoxide.

Third, by determining the density of gaseous compounds of carbon.

The first of these methods was used by Dumas and Stas [3] in 1840, and a year later by Erdmann and Marchand.[4] In both investigations weighed quantities of diamond, of natural graphite, and of artificial graphite were burned in oxygen, and the amount of dioxide produced was determined by the usual methods. The graphite employed was purified with extreme care by treatment with strong nitric acid and by fusion with caustic alkali. I have reduced all the published weighings to a common standard, so as to show in the third column the amount of oxygen which combines with a unit weight (say 1 gramme) of carbon. Taking Dumas and Stas' results first in order, we have from natural graphite:

C.	*CO_2.*	*Ratio.*
1.000	3.671	2.6710
.998	3.660	2.6673
.994	3.645	2.6670
1.216	4.461	2.6686
1.471	5.395	2.6676
		Mean, $2.6683 \pm .0005$

[1] For a general discussion of the atomic weight of N, see Guye's lecture delivered before the Chemical Society of Paris, June 10, 1905. Also Compt. Rend., 140, 1386, and 144, 1360; and Ber., 39, 1470. Two papers by Berthelot, of a controversial nature, are in Compt. Rend., 144, 76 and 269, and one by Leduc in Compt. Rend., 146, 399.

[2] Compt. Rend., 147, 925. 1908.

[3] Compt. Rend., 11, 991. Ann. Chim. Phys. (3), 1, 1.

[4] Journ. prakt. Chem., 23, 159.

With artificial graphite:

C.	CO_2.	*Ratio.*
.992	3.642	2.6714
.998	3.662	2.6693
1.660	6.085	2.6657
1.465	5.365	2.6621
		Mean, 2.6671±.0014

And with diamond:

C.	CO_2.	*Ratio.*
.708	2.598	2.6695
.864	3.1675	2.6661
1.219	4.465	2.6628
1.232	4.517	2.6664
1.375	5.041	2.6662
		Mean, 2.6662±.0009

Erdmann and Marchand's figures for natural graphite give the following results:

C.	CO_2.	*Ratio.*
1.5376	5.6367	2.6659
1.6494	6.0384	2.6609
1.4505	5.31575	2.6647

In one experiment 1.8935 grammes of artificial graphite gave 6.9355 grammes CO_2. Ratio for O, 2.6628. This, combined with the foregoing series, gives a mean of 2.6636±.0007.

With the diamond they found:

C.	CO_2.	*Ratio.*
.8052	2.9467	2.6596
1.0858	3.9875	2.6632
1.3557	4.9659	2.6629
1.6305	5.97945	2.6673
.7500	2.7490	2.6653
		Mean, 2.6637±.0009

In more recent years the ratio under consideration has been carefully redetermined by Roscoe, by Friedel, and by Van der Plaats. Roscoe [1] made use of transparent Cape diamonds, and in a sixth experiment he burned carbonado. The combustions were effected in a platinum boat, contained in a tube of glazed Berlin porcelain; and in each case the ash was weighed and its weight deducted from that of the diamond. The results were as follows, with the ratios stated as in the preceding series:

C.	CO_2.	*Ratio.*
1.2820	4.7006	2.6666
1.1254	4.1245	2.6649
1.5287	5.6050	2.6665
.7112	2.6070	2.6656
1.3842	5.0765	2.6675
.4091	1.4978	2.6612
		Mean, 2.6654 ± .0006

Friedel's work,[2] also upon Cape diamond, was in all essential particulars like Roscoe's. The data, after deduction of ash, were as follows:

C.	CO_2.	*Ratio.*
.4698	1.7208	2.6628
.8616	3.1577	2.6649
		Mean, 2.6638 ± .0004.

By Van der Plaats [3] we have six experiments, numbers 1 to 3 on graphite, numbers 4 and 5 on sugar charcoal, and number 6 on charcoal made from purified filter paper. Each variety

[1] Ann. Chim. Phys. (5), 26, 136. Zeit. anal. Chem., 22, 306. 1883. Compt. Rend., 94, 1180. 1882.
[2] Bull. Soc. Chim., 41, 100. 1884.
[3] Compt. Rend., 100, 52. 1885.

of carbon was submitted to elaborate processes of purification, and all weights were reduced to a vacuum standard. The data, with ash deducted, are subjoined:

C.	*CO_2.*	*Ratio.*
1. 5.1217	18.7780	2.6664
2. 9.0532	33.1931	2.6664
3. 13.0285	47.7661	2.6663
4. 11.7352	43.0210	2.6660
5. 19.1335	70.1336	2.6655
6. 4.4017	16.1352	2.6657
		Mean, 2.6660 ± .0001.

This combines with the previous series thus:

	Ratio.	*Atomic weight C.*
Dumas and Stas, first set	2.6683 ± .0005	11.9926
Dumas and Stas, second set	2.6671 ± .0014	11.9981
Dumas and Stas, third set	2.6662 ± .0009	12.0031
Erdmann and Marchand, first set	2.6636 ± .0007	12.0138
Erdmann and Marchand, second set	2.6637 ± .0009	12.0134
Roscoe	2.6654 ± .0006	12.0057
Friedel	2.6638 ± .0007	12.0129
Van der Plaats	2.6660 ± .0001	12.0030
General mean	2.6660 ± .0001	12.0030 ± .0005.

The effect of this combination is to give the work of Van der Plaats overwhelming weight, to which it is perhaps not entitled. The other determinations practically vanish.

According to Scott [1] all of the foregoing determinations are subject to an important correction, namely, a reduction to weight in vacuo. This correction was applied by Van der Plaats, at least partially, but Scott lays emphasis upon the change in volume of the potash solution in which the carbon dioxide was absorbed and weighed. The corrections, as applied by Scott, are given in the following table, in which the total reduced weights of carbon and dioxide are used instead of the individual weights of the separate experiments:

	Total C.	*Total CO_2.*	*Ratio.*	*Atomic weight.*
Dumas and Stas	16.1994	59.4201	2.66804	11.9938
Erdmann and Marchand	12.1636	44.58537	2.66547	12.0054
Roscoe	6.4428	23.6275	2.66727	11.9973
Friedel	1.33185	4.8818	2.66543	12.0056
Van der Plaats	62.5115	229.1836	2.66630	12.0017

If to these figures we assign the relative weights given in the previous combination the final mean will be identical with that of Van der Plaats as before, and C = 12.0017, ±.0005. Scott adopted the unweighted average of the five series given above, and made C = 12.0008.

The second method for determining the atomic weight of carbon was employed by Stas [2] in 1849. Carefully purified carbon monoxide was passed over a known weight of copper oxide at a red heat, and both the residual metal and the carbon dioxide formed were weighed. The weighings were reduced to a vacuum standard, and in each experiment a quantity of copper oxide was taken representing from eight to twenty-four grams of oxygen. The method, as will at once be seen, is in all essential features similar to that usually employed for determining the composition of water. The figures in the third column, deduced from the weights given by Stas, represent the quantity of carbon monoxide corresponding to one gramme of oxygen:

O	*CO_2.*	*Ratio.*
9.265	25.483	1.75046
8.327	22.900	1.75010
13.9438	38.351	1.75040
11.6124	31.935	1.75008
18.763	51.6055	1.75039
19.581	53.8465	1.74994
22.515	61.926	1.75043
24.360	67.003	1.75053
		Mean, 1.75029 ± .00005.

[1] Journ. Chem. Soc., 71, 550. 1897.

[2] Bull. Acad. Belg., 1849 (1), 31. Oeuvres Complètes, 1, 287.

Hence CO = 28.0046, and C = 12.0046 ± .0008.

This work of Stas was also criticized by Scott,[1] in connection with the determinations by the first method. The process employed is subject to several possible errors, two of them being especially serious. First, the carbon monoxide may have contained hydrogen or hydrocarbons. Secondly, the copper oxide, which was prepared by calcining copper nitrate, almost certainly occluded nitrogen. The value found for C, however, is probably not very far from the truth, and it is not unlikely that errors in opposite directions tended to compensate one another.

For the density of carbon monoxide there are available determinations by Leduc[2] and Rayleigh.[3] Leduc used a globe which had a capacity of 2.9440 grammes of air. Filled with CO it held the following weights, giving the accompanying densities:

Weight CO.	*Density.*
2.8470	.96705
2.8468	.96698
2.8469	.96702
	.96702 ± .000015.

This density, combined with Leduc's determination of the density of oxygen, 1.10514 ± .000032, gives the crude ratio—

$$O_2 : CO :: 32 : 28.0007 \pm .0010.$$

Rayleigh's determinations may be stated in the following form: A globe which held 2.62760 ± .00004 grams of oxygen, held of carbon monoxide—

2.29843
2.29852
2.29854

Mean, 2.29850 ± .000024.

Corrected for the compression of the globe when empty this becomes 2.29906 ± .000024. From these data the crude value for CO is 27.9989 ± .0012. Combining this with Leduc's determination the general mean becomes—

$$CO = 28.0000 \pm .00077.$$

Rayleigh, it must be observed, prepared his three samples of carbonic oxide by three distinct methods, and the concordance in their weights gives strong assurance of their purity.

For the calculation of the true molecular weight of carbon monoxide from this crude density ratio, the critical data cited by Guye[4] are available. The mean of two sets of critical constants gives $(1+a)(1-b) = 1.00109$, and $T = 132.7°$. Applying these figures by the formula given under nitrogen, the molecular weight becomes

$$CO = 28.0031 \pm .00077.$$

The density of carbon dioxide has been determined by many investigators,[5] but the earliest measurements have now only historical interest. In 1845 Regnault[6] published five determinations of the density, referred to air as unity, and they were the first to be worth consideration now. His figures are as follows:

1.52915	1.52906
1.52900	1.52915
1.52915	

Mean, 1.52910 ± .000032

[1] *Loc. cit.* See also Richards, Amer. Chem. Journ., 20, 701. 1898.
[2] Compt. Rend., 115, 1072. 1893.
[3] Proc. Roy. Soc., 62, 204. 1897.
[4] Journ. Chim. Phys., 3, 342. 1905.
[5] The early determinations are well summarized in Van Geun's monograph.
[6] Compt. Rend., 20, 993. 1845.

Corrected by Crafts,[1] for compression of the empty globe, this becomes $1.52897 \pm .000032$. For the density of oxygen, Regnault's corrected value is $1.10562 \pm .000008$.

Hence $O_2 : CO_2 : : 32 : 44.2530 \pm .00098$.

In three concordant measurements, which are not given separately, Leduc [2] found for CO_2 the density 1.52874. This figure, combined with his value for oxygen, already cited, gives for CO_2 the density ratio 32 : 44.2667. Rayleigh [3] gives a single figure for the density of CO_2, namely, 1.52909. For oxygen he found 1.10535. Hence the ratio 32 : 44.2673.

The three determinations by Guye and Pintza [4] are stated in the form of normal litre-weights, as follows:

1.97684
1.97676
1.97681
Mean, $1.97680 \pm .0000176$

With the accepted figure for the weight of a litre of oxygen, $1.42905 \pm .000013$, the ratio becomes

$$O_2 : CO_2 :: 32 : 44.2654 \pm .00071.$$

To the values deduced from Leduc's and Rayleigh's data we may arbitrarily assign equal weight with the mean of Regnault's series. The four determinations then combine thus:

Regnault	$44.2530 \pm .00098$
Leduc	$44.2667 \pm .00098$
Rayleigh	$44.2673 \pm .00098$
Guye and Pintza	$44.2654 \pm .00071$
General mean	$44.2632 \pm .00038$

Regnault's figure is probably too low. Its omission would raise the general mean to 44.2674 but such a procedure is questionable. I prefer therefore to leave the combination unchanged, except for the necessary reduction by means of the critical constants. For these, based on the mean of determinations by Amagat and Keesom, Guye [5] deduces $(1+a_0)\ (1-b_0) = 1.00687$. Applying this value we have for the molecular weight under consideration,

$$CO_2 = 43.9966 \pm .00038.$$

There are a few other data relative to the oxides of carbon yet to be considered. Rayleigh [6] has compared the density of carbon monoxide at atmospheric pressure with its density at pressures between 75 and 150 millimeters of mercury. The molecular weights deduced are, for normal pressure, $CO = 28.000$, for low pressures, 28.006, when $O = 16$. Hence $C = 12.006$.

A comparison of the gases at high temperatures has been made by Jaquerod and Perrot.[7] They measured the expansion of the two carbon oxides up to 1067.4°, applied their results to the mean densities found by Leduc and Rayleigh, and obtained the following molecular values:

$CO = 28.009$, and $C = 12.009$.
$CO_2 = 43.992$, and $C = 11.992$.

These figures are interesting for comparison with those previously discussed, but can hardly be used in a general combination.

Another group of data from which the carbon-oxygen ratio can be deduced is found in the density determinations of certain organic compounds. The older measurements need not be considered, but three recent investigations have some value.

[1] Compt. Rend., 106, 1664.
[2] Ann. Chim. Phys. (7), 15, 34. 1898.
[3] Proc. Roy. Soc., 62, 204. 1897.
[4] Compt. Rend., 141, 51. 1905.
[5] Journ. Chim. Phys., 3, 337. 1905.
[6] Proc. Roy. Soc., 73, 153. 1904.
[7] Compt. Rend., 140, 1542. 1905.

First, the density of methyl oxide $(CH_3)_2O$, as determined by Baume.[1] Two series are given, with the subjoined values for the weight of a normal litre:

I.	*II.*
2.10912	2.10925
2.10886	2.10941
2.11045	2.11026
2.10920	2.10936
2.10948	2.11005
2.11003	2.10977
2.10947	
Mean, 2.10951 ± .00014	Mean, 2.10968 ± .00011

A small correction raises these means by 0.00001. Combined, the final value is 2.10961 ± .000084. With the critical data given by Baume, $a_o = 0.03111$, and $b_o = 0.00382$. Reducing these figures by means of the formula already cited, the molecular weight of methyl oxide becomes 46.0306 ± .0021. Hence, with H = 1.0078,

$$C = 11.9919 \pm .0010$$

a value which is almost certainly too low.

For the weight of a normal litre of methane, CH_4, Baume and Perrot[2] find the following values:

0.71690	0.71636
0.71657	0.71672
0.71633	0.71678
0.71669	0.71725
0.71751	

Mean, 0.71689 ± .000098

Reducing this with the critical constants determined by Guye, $CH_4 = 16.034 \pm .0022$. Hence

$$C = 12.0028 \pm .0022.$$

The density of ethane, C_2H_6, has also been determined by Baumé and Perrot.[3] Two series of measurements were made, giving the subjoined figures for the weight of the normal liter:

I.	*II.*
1.35671	1.35600
1.35679	1.35610
1.35671	1.35653
1.35652	1.35640
1.35700	1.35590
1.35640	1.35640

Mean of all as one series, 1.356455 ± .000065. Reducing their data by means of the critical constants, the authors find $C_2H_6 = 30.119$, and C = 12.036. This value is evidently too high.

From the density of toluene, Leduc[4] has recently deduced the value 12.003. The determination, however, is not sufficiently explicit in detail to admit of its use for present purposes. Another value is calculable from Parson's glucinum ratios;[5] namely, C = 12.007.

There is also a preliminary note, by Scott,[6] which gives, without details, the results of combustions of naphthalene and cinnamic acid. In six analyses, 17.6175 grammes of naphthalene gave 60.5355 of CO_2. Hence C = 11.999. In two analyses, 8.6153 grammes of cinnamic acid gave 23.0413 of CO_2. Hence C = 12.0015.

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[1] Journ. Chim. Phys., 6, 46. 1908. Baume also gives data for methyl chloride, but they are not available for a good determination of molecular weight.

[2] Compt. Rend., 148, 39. 1909.

[3] Compt. Rend. 148, 832. 1909.

[4] Compt. Rend., 148, 832. 1909.

[5] See section on glucinum, later.

[6] Proc. Chem. Soc., 25, 310.

Rejecting the aberrant value for C derived from the density of ethane, we have six available values to combine, as follows:

From combustion of carbon	$C=12.0017\pm.0005$
From combustion of CO	$C=12.0046\pm.0008$
From density of CO	$C=12.0031\pm.0008$
From density of CO_2	$C=11.9966\pm.0004$
From density of CH_4	$C=12.0028\pm.0022$
From density of $(CH_3)_2O$	$C=11.9919\pm.0010$
General mean	$C=12.0000\pm.00026$

Later, in the discussion of all the fundamental ratios this value for carbon will be slightly modified by values derived from data based upon the study of several silver compounds, and also of sodium carbonate.

ADDENDA.

Since the foregoing calculations were completed, two additional memoirs on the atomic weight of carbon have appeared. Stahrfoss [1] has determined the density of acetylene, ethylene, and ethane. For ethylene, C_2H_4, the following values for the weight of the normal liter are—

1.26061
1.26178
1.26063
Mean, 1.26101

Hence, according to Stahoposs, who reduced his data by the method of critical constants, C = 12.004.

For ethane two series of determinations are given, as follows:

1.	*2.*
1.35632	1.35684
1.35621	1.35701
1.35668	1.35687
1.35585	
Mean, 1.35627	Mean, 1.35690

From the mean of all seven determinations, reduced by means of the critical constants, Stahrfoss finds C = 12.006. He also applies corrections to the data given by Baumé and Perrot, and from them finds for the weight of the normal liter of ethane the value 1.35650, which is in good agreement with his own measurements.

The determinations by Stahrfoss of the density of acetylene were not used in computing the atomic weight of carbon, because of the tendency of the gas to polymerize and so to become abnormally heavy.

The density of ethylene has also been determined by Batuecas,[2] who obtained the following values for the weight of the normal liter.

Preliminary series.

1.25985
1.26033

Final series.

1.26047	1.26047
1.25999	1.26050
1.26041	1.26052
1.26002	1.26012
1.26022	1.26037
1.26052	1.26047
1.26045	1.26029
1.26029	1.26046
1.26003	1.26031
1.26031	

Mean of both series, $1.2603\pm.0001$.

[1] Journ. Chim. Phys., 16, 175. 1918.

[2] Journ. Chim. Phys., 16, 322. 1918.

From the figures, by two methods of reduction, Batuecas obtains the following values for the molecular weight of ethylene:

By molecular volumes	$C_2H_4=28.022$
By critical constants	$C_2H_4=28.030$
Mean	$C_2H_4=28.026$

Hence, if H = 1.0078, C = 11.9974.

To combine these new values for carbon with the general mean found in the final computations is hardly necessary. They would change the ultimate value inappreciably.

SYNTHESES AND DENSITY OF HYDROCHLORIC ACID.

The quantitative synthesis of hydrochloric acid, with reference to the atomic weight of chlorine, was first effected by Dixon and Edgar.[1] Chlorine, prepared by the electrolysis of fused silver chloride, was weighed in liquid form. Hydrogen, obtained electrolytically from barium hydrate, was occluded by palladium, and so weighed. A combustion globe was filled with the chlorine, and the hydrogen, ignited by a spark, was burned in it. The excess of chlorine was determined by absorption in potassium iodide, and subsequent titration of the liberated iodine with thiosulphate solution. With corrected weights the following results were obtained:

Weight H.	*Weight Cl.*	*Ratio Cl:H.*
0.9993	35.1666	35.191
1.0218	35.9621	35.195
.9960	35.0662	35.207
1.0243	36.0403	35.185
1.0060	35.4144	35.203
.9887	34.8005	35.198
1.0159	35.7639	35.204
1.1134	39.1736	35.184
1.0132	35.6527	35.188
		Mean, 35.195 ±.0019

The determinations by Noyes and Weber[2] were differently conducted. The hydrogen was weighed in palladium; but the chlorine was taken in the form of potassium chloroplatinate. That salt was heated in a stream of hydrogen, and the loss in weight gave the weight of chlorine taken. The hydrochloric acid produced was also collected and weighed.

Two series of experiments were made, differing in detail. In series I, the hydrogen was prepared by electrolysis of sulphuric acid, and in series II from barium hydroxide. The hydrochloric acid of series I was collected in water directly; but in series II it was first condensed to a solid by cooling with liquid air. The two series, however, were concordant, and may therefore be treated here as one. The data obtained, reduced to a vacuum basis, were as follows:

H.	*Cl.*	*HCl.*	*Cl:H.*	*HCl:H*
0.25394	8.93293	9.18695	35.177	36.178
.28004	9.85590	10.13259	35.195	36.183
.51821	18.23468	18.75359	35.188	36.189
.67631	23.79587	24.47123	35.185	36.183
.58225	20.48158	.....	35.177	.....
.47989	16.88423	17.36310	35.184	36.181
.64132	22.55816	23.20054	35.175	36.176
.81608	28.71691	29.53167	35.188	36.187
.83194	29.28055	30.11207	35.195	36.195
.39074	13.74926	14.14078	35.188	36.188
.75560	26.58427	27.33926	35.183	36.182
.77518	27.26746	28.04110	35.176	36.174
			Mean, 35.1843	36.1835
			±.0014	±.0013

[1] Phil. Trans., 205A, 169. 1905.

[2] Journ. Amer. Chem. Soc., 30, 13. 1908.

Edgar's [1] syntheses of hydrochloric acid resembled those of Dixon and Edgar, so far as the preparation and weighing of the initial substances were concerned. The chlorine was then burned in the hydrogen, at the end of a quartz tip, and the hydrochloric acid so produced was condensed to solid form by means of liquid air. It was afterwards allowed to evaporate, and passed through a quartz tube filled with mercury vapor, which removed any free chlorine. The purified hydrochloric acid was finally condensed, either in a steel bomb or by absorption in water, and weighed. The corrected weights and ratios are subjoined:

H.	*Cl.*	*HCl.*	*Cl:H.*	*HCl:H.*
2.1452	75.5026	77.6469	35.196	36.196
2.0387	71.7504	73.7880	35.194	36.194
1.7762	62.5004	.....	35.188	.....
1.9935	70.1638	72.1565	35.196	36.196
1.6469	57.9671	.....	35.198	.....
2.1016	73.9662	.....	35.195	.....
1.7254	60.7162	62.4401	35.190	36.189
2.0885	73.4991	75.5859	35.192	36.191
			Mean, 35.194	36.193
			±.0008	±.0009

Upon reducing the HCl:H ratios to the Cl:H form the five sets of determinations combine thus:

Dixon and Edgar, H:Cl	35.195 ±.0019
Noyes and Weber, H:Cl	35.1843±.0014
Noyes and Weber, H:HCl	35.1835±.0013
Edgar, H:Cl	35.194 ±.0008
Edgar, H:HCl	35.193 ±.0009
General mean,	35.1911±.00049

That is, the atomic weight of chlorine, when H = 1, is 35.1911. If O = 16, then Cl = 35.4652 ±.0005.

For the weight of a normal liter of hydrochloric acid, Guye and Ter Gazarian [2] give the subjoined figures:

1.6404	1.6389
1.6397	1.6401

Mean, 1.6398±.00007

Reducing these by the method of critical constants, in which the term $(1+a_0)\ (1-b_0) = 1.00773$, the molecular weight of HCl becomes 36.4693±.0015. Hence, if H = 1.0078, Cl = 35.4615±.0015.

The work of Gray and Burt [3] on the chlorine-hydrogen ratio is much more elaborate. First, three series of determinations of the density of HCl are given, with the weight of one liter of the gas at 0°, 760 mm., and at London, as follows:

I.	*II.*	*III.*
1.64053	1.64022	1.63950
1.64004	1.63999	1.64013
1.64020	1.63976	1.63984
1.63986	1.64083	1.64069
———	1.64030	1.64031
Mean, 1.64016	1.64021	1.64017
±.00010	1.64027	1.64050
	———	1.64051
	Mean, 1.64023	1.63992
	±.00008	1.64001
		———
		Mean, 1.64016
		±.00008

[1] Proc. Roy. Soc., 81A, 216. 1908.

[2] Compt. Rend., 143, 1233. 1906. A single determination of the density of HCl by Leduc (Ann. Chim. Phys. (7), 15, 1. 1898) can hardly be utilized here.

[3] Journ. Chem. Soc., 95, 1633. 1909.

The three series represent hydrochloric acid prepared by three distinct methods. Series I and II are to be corrected by -0.00013 gramme, which represents gas absorbed by the walls of the containing glass bulb. The corrected mean becomes $1.64011 \pm .00005$ grams, which, at sea level and latitude 45° is equivalent to 1.63915 grammes, the weight of the normal liter. If we reduce this with the critical constants used by Guye and Ter Gazarian,[1] it gives HCl = 36.4548, and with H = 1.0078, Cl = $35.4470 \pm .0011$, a very low value.

In order to ascertain the atomic weight of chlorine, Gray and Burt have measured the compressibility of the HCl, and also determined its composition by volume. In the latter case the gas was decomposed by heated aluminum, and the volume of hydrogen liberated from two volumes of hydrochloric acid was measured. The volumes thus found were as follows:

1.00797	1.00781
1.00795	1.00779
1.00790	1.00787
1.00790	1.00798

Mean, $1.00790 \pm .000017$.

Using Morley's value for the weight of a liter of hydrogen, $0.089872 \pm .0000028$ gramme, and with the atomic weight $H = 1.0078 \pm .00001$, the molecular weight of HCl is given by the following equation:

$$\frac{1.63915}{0.089872} \times \frac{2}{1.00790} \times 1.0078 = 36.4738$$

and $Cl = 35.4658 \pm .0013$. Gray and Burt, calculating with H = 1.00762 (Morley's value), find Cl = 35.459.

The data given by Gray and Burt for the compressibilities of oxygen and hydrochloric acid are too complex to admit of detailed reproduction here. The normal liter of oxygen, weighing 1.42905 grammes, gave a limiting density of 1.42762 grammes. That of HCl, 1.63915 grammes, gives a limiting density of 1.62698 grammes. The ratio between these limiting densities is the true ratio between the molecular weights according to Avogadro's law. Hence,

$$\frac{1.62698 \times 32}{1.42762} = \text{Mol. Weight HCl} = 36.4687$$

Hence, assuming the probable errors 0.00005 for HCl, and 0.000013 for O_2, $Cl = 35.4609 \pm .0014$.

The three values derived from Gray and Burt's determinations, now give the subjoined values for the molecular weight of HCl, when H = 1.0078.

By critical constants	HCl = $36.4548 \pm .0011$
By volumetric analysis	$36.4738 \pm .0013$
By compressibility measurements	$36.4687 \pm .0014$
General mean	HCl = $36.4640 \pm .0007$

Hence, $Cl = 35.4562 \pm .0007$. Gray and Burt, from their two methods alone, find Cl = 35.460. The difference between their figure and the foregoing combination is only one part in 9332, which is less than the actual uncertainty.

Determinations of the density of HCl have also been made by Scheuer.[2] By simultaneous weighings of the gas in six globes, 28 values were obtained for the weight of the normal liter, as follows:

1.63935	1.63983	1.63943	1.63941
1.63959	1.63932	1.63943	1.63944
1.63939	1.63887	1.63933	1.63895
1.63940	1.63977	1.63933	1.63928
1.63968	1.63951	1.63931	1.63962
1.63945	1.63892	1.63942	1.63932
1.63987	1.63938	1.63968	1.63928

Mean of all, as one series, $1.63941 \pm .000031$.

[1] Gray and Burt do not make this calculation. It is useful, however, for purposes of comparison.

[2] Journ. Chim. Phys., 8,289, 1910. Zeitsch phys. Chem. 58, 575.

Scheuer reduces his measurements by three methods, with the following results:

By critical constants	HCl=36.455
By limiting densities	HCl=36.474
By molecular volumes	HCl=36.473
Mean	HCl=36.4673

Hence, if H=1.0078, Cl=35.4595±.00065. Scheuer himself rejects the value derived from the critical constants, and concludes that Cl=35.466. The lower value as given above is more consistent with other values for chlorine, and will be retained here.

In 1911 Burt and Gray [1] published a new series of determinations of the density of hydrochloric acid, with new precautions against error. Their figures for the weight of the normal liter at 0°, 760 mm., and at London are as follows:

1.63977	1.63892
1.63999	1.64009
1.64007	1.64016
1.63999	1.64037
1.64049	1.64030

Mean, 1.64011±.00005.

Reduced to sea level and latitude 45° this becomes 1.63915±.00005, a value identical with that found in the earlier investigations. The value for chlorine derived from it, and calculated in the same way, is also the same, namely, 35.4562±.0007. Burt and Gray, by their method of reduction, conclude that Cl=35.460.

Two years later Scheuer [2] issued another series of determinations, of which the full details seem not to have been published. His figures for the weight of a liter of hydrochloric acid are as follows:

1.63980	1.63986	1.63965	1.63952
1.63949	1.63963	1.63984	1.63978
1.63967	1.63980	1.63973	1.63968
1.63970	1.63942	1.63970	1.63975

Mean, 1.63969±.000021.

Corrected for latitude and elevation this becomes 1.63917±.000021, the weight of the normal liter. Reduced in the same manner as were his former determinations, this gives HCl =36.4687, and Cl=35.4609±.00047. The difference between this value and that obtained by Burt and Gray is due to the different methods of reduction. If reduced in the same way nearly identical values for the atomic weight of chlorine should be obtained. The physical constants employed by Scheuer are not the same as those used by Burt and Gray.

With the six values for the atomic weight of chlorine, as given in the preceding pages, the determination derived by Guye and Fluss from analyses of nitrosylchloride may also be combined. The details of this determination are given in the next section of this work. The general combination is as follows:

By syntheses of HCl	Cl=35.4652±.0005
Guye and Ter Gazarian	Cl=35.4615±.0015
Gray and Burt	Cl=35.4562±.0007
Scheuer, earlier series	Cl=35.4595±.00065
Burt and Gray	Cl=35.4562±.0007
Scheuer, later series	Cl=35.4609±.00047
Guye and Fluss	Cl=35.4680±.0010
General mean	Cl=35.4598±.00025

This final mean is practically identical with the value adopted in recent years by the International Committee on Atomic Weights, namely, Cl=35.460.

[1] Chem. News, 103, 161 and 170. 1911.

[2] Anzeiger Wien Akad., 50, 378. 1913

In the foregoing discussion, and also in the preceding discussion of the data relative to nitrogen, it is apparent that determinations of atomic weight by physical methods are capable of a high degree of accuracy. They are not, however, superior to the purely chemical determinations. In both general methods there is the fundamental difficulty of insuring the absolute purity of the substances that are employed. In the physical methods there are also the uncertainties as to the exact values of the physical constants. Critical constants, measurements of compressibility, and measurements of volume are all subject to experimental errors; and their determinations by different workers do not always agree. Such determinations impose their errors upon the values given by them for atomic or molecular weights; and the "probable errors" assigned to the latter are therefore too low. When both lines of investigation converge to a common value for an atomic weight the results obtained are probably close to the truth, but neither line can claim superiority over the other.

ANALYSES AND DENSITY OF NITROSYL CHLORIDE.

The analyses of nitrosyl chloride, NOCl, by Guye and Fluss,[1] are of special interest, because they give direct ratios between the three component elements. The carefully purified chloride was first weighed, and then distilled over heated silver, which absorbed the chlorine. The weight of the latter was given by the gain in weight of the silver. It was next passed over heated copper, which retained oxygen, and finally over metallic calcium to fix the nitrogen. The sum of the three components was generally a little less than that of the nitrosyl chloride, but whether the loss represents undetermined impurity, or failure to collect all the products of decomposition, seems to be uncertain. The weights obtained were as follows:

NOCl.	*Cl.*	*O.*	*N.*	*Loss.*
.5341	.2893	.1305	.1142	.0001
.4284	.2319	.1046	.0916	.0003
.7995	.4331	.1954	.1710	.0000
.5639	.3048	.1375	.1204	.0012
.5121	.2773	.1251	.1095	.0002

From these figures, with O = 16, the atomic weights of N and Cl are directly calculable, by comparison with O = 16. In a third column I also give the value of the ratio Cl : N : : 100 : x, computed from columns 2 and 4.

N.	*Cl.*	*Cl:N.*
14.001	35.470	39.475
14.011	35.472	39.500
14.002	35.464	39.483
14.010	35.468	39.501
14.005	35.466	39.488
Mean, 14.006 ± .0017	35.468 ± .0010	39.489 ± .0033

Several other ratios are calculable from the data given, and indeed, were computed by Guye and Fluss; but they are not needed here. They involve to a greater extent the uncertainties due to the losses from the initial substance. The direct value for chlorine has already been utilized in the preceding section of this work; that for nitrogen is negligible. Its influence upon the general combination does not even affect the fourth decimal place.

The synthesis of nitrosyl chloride has been effected by Wourtzel.[2] By the direct union of chlorine and nitric oxide he obtained the following weights; the ratio Cl : NO : : 100 : x has been added by myself.

Cl.	*NO.*	*Ratio.*
2.1670	1.83375	84.622
1.7751	1.5022	84.626
2.5632	2.16915	84.627
2.25865	1.91135	84.624
2.8994	2.45385	84.633
		Mean, 84.626 ± .0013.

[1] Journ. Chim. Phys., 6,732. 1908.

[2] Journ. Chim. Phys., 11, 214. 1913.

The density of nitrosyl chloride has also been determined by Wourtzel.[1] For the weight of one liter of the gas (at 0° and 760 mm.?) he gives the following figures, each one the mean of three series. Three discordant values are rejected.

2.9880	2.9877
2.9886	2.9888
2.9880	2.9875

Mean, 2.9881 ± .00014.

Wourtzel also gives a series of determinations at 287 mm. pressure, from which in mean one liter of the gas weighs 2.9466 grammes. With these data he determined the weight of the normal liter of nitrosyl chloride to be 2.919 grammes and the molecular weight as—

$$NOCl = 65.457 \pm .0031,$$

The probable errors are computed by myself.

We now have, apart from the direct values found for nitrogen and chlorine, three new ratios to be used in this final discussion of these atomic weights. They are

$$Cl : N :: 100 : 39.489 \pm .0033.$$
$$Cl : NO :: 100 : 84.626 \pm .0013.$$
$$Cl + N = 49.457 \pm .0031.$$

The last of these ratios is of small significance. The sum of the values already assigned to N and Cl is

$$35.4598 + 14.0076 = 49.4674,$$

which differs from the third ratio by 1 part in 3410. This divergence is too large for the accurate determination of atomic weights.

THE RATIO HCl : NH_3.

Julius Thomsen,[2] for the purpose of fixing indirectly the ratio H : O, has made a series of determinations of the ratio HCl : NH_3, which may properly be used toward establishing the atomic weight of nitrogen. First, pure, dry, gaseous hydrochloric acid is passed into a weighed absorption apparatus containing pure distilled water. After noting the increase in weight, pure ammonia gas is passed in until a very slight excess is present, and the apparatus is weighed again. The excess of NH_3, which is always minute, is measured by titration with standard hydrochloric acid. In weighing, the apparatus is tared by one of similar form, and containing about the same amount of water. Three series of determinations were made, differing only in the size of the absorption apparatus; so that for present purposes the three may be taken as one. Thomsen considers them separately, and so gives greatest weight to the experiments involving the largest masses of material. I give his weighings, and also, as computed by him, the ratio $\frac{HCl}{NH_3}$.

	HCl.	NH_3.	*Ratio.*
First series	5.1624	2.4120	2.1403
	3.9425	1.8409	2.1416
	4.6544	2.1739	2.1411
	3.9840	1.8609	2.1409
	5.3295	2.4898	2.1406
	4.2517	1.9863	2.1405
	4.8287	2.2550	2.1414
	6.4377	3.0068	2.1411
	4.1804	1.9528	2.1407
	5.0363	2.3523	2.1410
	4.6408	2.1685	2.1411

[1] Journ. Chim. Phys., 11, 29. 1913.

[2] Zeitsch. physikal. Chem., 13, 398. 1894. For a criticism of Thomsen's work, see Acree and Brunel, Amer. Chem. Journ., 36, 117. See also Meyer and Seubert, Ber. 27, 2770.

	HCl.	NH_3.	*Ratio.*
Second series	11. 8418	5. 5302	2. 14130
	14. 3018	6. 6808	2. 14073
	12. 1502	5. 6759	2. 14067
	11. 5443	5. 3927	2. 14073
	12. 3617	5. 7733	2. 14118
Third series	19. 3455	9. 0360	2. 14094
	19. 4578	9. 0890	2. 14081
		Mean of all,	2. 14093 ± . 000053
		Reduced to a vacuum,	2. 1394

From the sums of the weights Thomsen finds the ratio to be 2.14087, or 2.13934 in vacuo.

Thomsen, it will be noticed, performed his syntheses in an aqueous solution. Baumé and Perrot [1] in a later investigation effected the direct union of the two gases. Omitting determinations, which they rejected as defective, their weights are as follows:

HCl.	NH_3.	*Ratio.*
1. 50409	0. 70245	2. 1412
1. 28613	. 60046	2. 1419
. 56766	. 26514	2. 1410
1. 47740	. 68995	2. 1413
2. 08181	. 97219	2. 1414
		Mean, 2. 14136 ± . 000092.

With H = 1.0078 and N = 14.0076, Thomsen's determinations give Cl = 35.4283. Baumé and Perrot's figures, on the other hand, give Cl = 35.4617, a much better value. It seems justifiable, therefore, to reject the work of Thomsen as of no present significance. In the final discussion of the fundamental ratios this one will be used to determine the atomic weights of both chlorine and nitrogen, and so distributing the errors.

SYNTHESES AND DENSITY OF HYDROBROMIC ACID.

The synthesis of hydrobromic acid has been effected by Weber [2] by essentially the same method as that followed by Noyes and Weber in their work on hydrochloric acid. There are, however, differences of detail, for which the original memoir should be consulted. The weights and ratios obtained are as follows:

H.	*Br.*	*HBr.*	*H:Br.*	*H:HBr.*
0. 77300	61. 28837	62. 06052	79. 2863	80. 2853
. 86060	68. 25033	69. 11144	79. 3055	80. 3061
. 77607	61. 54733	62. 32198	79. 3064	80. 3046
. 96927	76. 88221	77. 85135	74. 3197	80. 3195
1. 07545	85. 29562	86. 37092	79. 3114	80. 3114
. 99689	79. 06834	80. 06424	79. 3150	80. 3140
. 74966	59. 45275	60. 20500	79. 3063	80. 3097
. 98161	77. 85554	78. 83758	79. 3141	80. 3145
1. 00131	79. 39633	80. 39658	79. 2915	80. 2914
. 81983	65. 02140	65. 83867	79. 3108	80. 3077
			Mean, 79. 3067	80. 3064
			± . 0022	± . 0023

With H = 1, these two ratios give Br = 79.3067 and 79.3064, respectively. Combined they give, with 0 = 16 and H = 1.0078,

$$Br = 79.9260 \pm .0016$$

The only determinations of the density of hydrobromic acid suitable for modern atomic weight reductions are those made recently in Guye's laboratory by MM. Moles, [3] Reiman, [4] and Murray. [5]

[1] Compt. Rend., 155, 461. Journ. Chim. Phys., 11, 53. 1913.
[2] Journ. Amer. Chem. Soc., 34, 1294.
[3] Journ. Chim. Phys., 14, 389. 1916. A critical discussion by Guye precedes Moles' paper.
[4] Compt. Rend., 164, 44 and 180. 1917. Journ. Chim. Phys., 15, 293.
[5] Ibid., p. 182. Journ. Chim. Phys., 15, 334.

Moles prepared his hydrobromic acid by four distinct processes, namely: By the hydrolysis of PBr_3, the reaction between Br and H_2S, and the reactions between Br and naphthalene and Br and paraffin. With a gas thus obtained he made 33 determinations of the weight of one liter at 0° and 760 mm., as follows:

3. 64497	3. 64439	3. 64411
3. 64530	3. 64490	3. 64370
3. 64514	3. 64473	3. 64420
3. 64365	3. 64424	3. 64374
3. 64298	3. 64600	3. 64480
3. 64608	3. 64437	3. 64420
3. 64374	3. 64462	3. 64423
3. 64528	3. 64404	3. 64480
3. 64400	3. 64395	3. 64477
3. 64569	3. 64475	3. 64326
3. 64369	3. 64403	3. 64450

Mean, $3.64442 \pm .00013$.

Moles also made 11 determinations of the weight of a liter of the gas at 506.67 mm. pressure, and 17 at 253.33 mm. The mean weights were 3.63314 and 3.62190 grams, respectively. From these data, by formulæ which he gives in detail, he finds—

$$HBr = 80.9333,$$

where, if $H = 1.0078$, $Br = 79.9255$. Moles assumes that $H = 1.0076$, which gives a slightly higher value for bromine.

Reiman prepared his hydrobromic acid by the action of syrupy phosphoric acid on potassium bromide. He gives 12 determinations for the weight of one liter, at standard temperature and pressure, as follows:

3. 6436	3. 6435
3. 6442	3. 6433
3. 6442	3. 6445
3. 6461	3. 6442
3. 6457	3. 6439
3. 6435	3. 6440

Mean, $3.64422 \pm .0002$.

He, like Moles, also gives series of weights at reduced pressure.

Murray employed hydrobromic acid produced by the hydrolysis of $AlBr_3$, and gives 16 determinations of the weight of one liter as follows:

3. 6497	3. 6482
3. 6415	3. 6439
3. 6402	3. 6322
3. 6418	3. 6422
3. 6467	3. 6453
3. 6432	3. 6463
3. 6410	3. 6492
3. 6401	3. 6430

Mean, $3.6435 \pm .0005$.

Combining these series, we have—[1]

Moles	$3.64442 \pm .00013$
Reiman	$3.64422 \pm .0002$
Murray	$3.6435 \pm .0005$
General mean	$3.64431 \pm .00011$

as the weight of a standard litre of hydrobromic acid. Hence, reduced proportionally to Moles' determination,

$$HBr = 80.9310 \pm .0024,$$

and

$$Br = 79.9232 \pm .0024.$$

[1] From the data relative to the density of HBr, Guye (Journ. Chim. Phys., 17, 171) finds Br=79.920. In a previous paper (ibid, p. 141) he discusses the application of Avogadros's law to the density of HBr.

As a final combination we have, as the atomic weight of bromine,

By syntheses of HBr	Br=79.9260±.0016.
By density of HBr	Br=79.9232±.0024.
General mean	Br=79.9251±.0013.

IODINE PENTOXIDE RATIOS.

The complete analysis of iodine pentoxide has been effected by Guichard,[1] who determined thereby the direct ratio between iodine and oxygen. The pentoxide was decomposed at a high temperature, and the iodine set free was collected and condensed in a suitable tube, in which it was weighed. The oxygen was fixed on heated copper, and also weighed. The weights obtained are as follows:

I_2O_5.	I.	O.
5.18051	8.93910	1.24183
7.80826	5.93688	1.87138
9.33281	7.09689	2.23637
6.23324	4.73922	1.49333
7.08076	5.38441	1.69714

From these data three sets of values for the atomic weight of iodine can be computed.

$I:I_2O_5$.	$O:I_2O_5$.	$O:I$.
126.923	126.867	126.880
126.897	126.898	126.898
126.960	126.928	126.936
126.885	126.962	126.943
126.964	126.887	126.905
Mean, 126.926±.0108.	Mean, 126.908±.0112.	Mean, 126.912

Mean of all as one series, I=126.915±.0056.

The ratio between iodine pentoxide and silver has been measured by Baxter and Tilley.[2] The oxide was prepared by the careful dehydration of iodic acid, the latter having been made from purified iodine. After weighing, the pentoxide was dissolved in water, and the acid so formed was reduced to hydriodic acid by means of hydrazine. By final titration of the solution with a solution of pure silver, the ratio in question was determined. The ultimate data, with vacuum weights and all corrections applied, are as follows:

Series I.—Tilley.

Weight I_2O_5.	*Weight Ag.*	*Ratio.*
6.06570	3.92027[3]	64.6234
9.48035	6.12611	
7.73052	4.99564	64.6223
12.63909	8.16777	64.6231
9.49913	6.13841	64.6208
8.34369	5.39202	64.6239
8.83155	5.70715	64.6223
6.77487	4.37803	64.6216
		Mean, 64.6225±.0003

Series II.—Baxter.

Weight I_2O_5.	*Weight Ag.*	*Ratio.*
12.09036	7.81320	64.6234
6.29744	4.00957	64.6226
10.89880	7.04309	64.6226
9.33895	6.03505	64.6222
10.15370	6.56169	64.6236

[1] Compt. Rend., 159, 185, 1914. With details in Annales Chim. Phys., (9) 6, 279 and (9) 7, 5. 1916 and 1917.
[2] Journ. Amer. Chem. Soc., 31, 201. 1909.
[3] These analyses were inadvertently mixed, and are combined in the table.

Weight I_2O_5.	*Weight Ag.*	*Ratio.*
11.00453	7.11141	64.6226
7.01649	4.53431	64.6236
9.33573	6.03304	64.6231
8.72163	5.63619	64.6231
9.01524	5.82591	64.6229
		Mean, 64.6230±.0001

Combining both series, the mean value for the ratio is

$$I_2O_5:2Ag::100:64.2229\pm.0001$$

ANALYSES OF SODIUM HALIDES.

The chloride and bromide of sodium have been analyzed electrolytically by Goldbaum.[1] The salts were electrolyzed in a cell having mercury as the cathode, with a weighed anode of silver. The sodium formed an amalgam with the mercury, and the chlorine or bromine was firmly deposited on the silver. A trace of chlorine remained in solution, and was determined by means of the nephelometer. All weights were reduced to a vacuum.

Sodium chloride was analyzed in two series; the first one being "preliminary." The weights and percentage of Cl in NaCl are as follows. The percentages were computed by myself.

NaCl.	*Cl.*	*Per cent Cl.*
0.81495	0.49432	60.656
.79370	.48135	60.646
.88940	.53962	60.672
.45642	.27679	60.644
.43884	.26618	60.655
.44239	.26828	60.643
.64942	.39387	60.650
.53706	.32581	60.665
		Mean, 60.654±.0025

For the final series we have—

NaCl.	*Cl.*	*Per cent Cl.*
1.02234	0.62014	60.6587
1.02221	.62006	60.6587
2.43474	1.47692	60.6601
1.46370	.88789	60.6607
.56934	.34534	60.6562
1.00793	.61141	60.6600
1.06501	.64600	60.6567
2.16720	1.31460	60.6589
2.75219	1.66939	60.6568
.92900	.56349	60.6555
1.83527	1.11324	60.6581
		Mean, 60.6582±.00035
		Weighted mean of both series, 60.6581±.00035

For sodium bromide only one series of analyses was made, as follows:

Na Br.	*Br.*	*Per cent Br.*
1.05343	0.81803	77.6538
1.33360	1.03561	77.6554
1.95652	1.51936	77.6583
5.02976	3.90586	77.6550
2.09332	1.62554	77.6538
6.46697	5.02178	77.6528
5.54733	4.30768	77.6532
7.03901	5.46606	77.6538
		Mean, 77.6543±.00029

[1] Journ. Amer. Chem. Soc., 33, 35. 1911.

From these series of analyses the cross ratio between chlorine and bromine is calculable, giving

$$Br:Cl::100:44.3674 \pm .0006.$$

If $Cl = 35.4598$, the value previously found in this recalculation,

$$Br = 79.9221.$$

If $Br = 79.9251$, the value previously found, then

$$Cl = 35.4607.$$

This computation, based upon the new ratios gives strong evidence in favor of the accuracy of Goldbaum's work.

ANALYSES OF CHLORATES.

Until recent times the fundamental values for the atomic weights of silver, chlorine and potassium, were best determined through analyses of chlorates. Modern, direct determinations of the chlorine-hydrogen and nitrogen-oxygen ratios have in great measure supplanted the chlorate work, which, however, must still be taken into account, and may even regain some of the lost ground.

The first good series of analyses of potassium chlorate was made by Berzelius.[1] All the earlier estimations were vitiated by the fact that when potassium chlorate is ignited under ordinary circumstances a little solid material is mechanically carried away with the oxygen gas. Minute portions of the substance may even be actually volatilized. These sources of loss were avoided by Berzelius, who devised means for collecting and weighing this trace of potassium chloride. All the successors of Berzelius in this work have benefited by his example, although for the methods by which loss has been prevented we must refer to the original papers of the several investigators. In short, then, Berzelius ignited potassium chlorate, and determined the percentage of chloride which remained. Four experiments gave the following results:

60.854	60.850
60.850	60.851

Mean, 60.851, ±.0006

The next series was made by Penny,[2] who worked after a somewhat different method. He treated potassium chlorate with strong hydrochloric acid in a weighed flask, evaporated to dryness over a sand bath, and then found the weight of the chloride thus obtained. His percentages are as follows, in six trials:

60.825	60.820
60.822	60.823
60.815	60.830

Mean, 60.8225, ±.0014

In 1842 Pelouze[3] made three estimations by the ignition of the chlorate, with these results:

60.843
60.857
60.830

Mean, 60.843±.0053

Marignac, in 1842,[4] worked with several different recrystallizations of the commercial chlorate. He ignited the salt, with the usual precautions for collecting the material carried off mechanically, and also examined the gas which was evolved. He found that the oxygen from 50 grammes of chlorate contained chlorine enough to form 0.003 gramme of silver chloride. Here are the percentages found by Marignac:

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[1] Poggend. Annalen, 8, 1. 1826.
[2] Phil. Trans., 1839, p. 20.
[3] Compt. Rend., 15, 959.
[4] Ann. Chem. Pharm., 44, 18. Oeuvres Complètes, 1, 57.

In chlorate once crystallized	60.845
In chlorate once crystallized	60.835
In chlorate twice crystallized	60.833
In chlorate twice crystallized	60.844
In chlorate three times crystallized	60.839
In chlorate four times crystallized	60.839

Mean, 60.8392±.0013

In the same paper Marignac describes a similar series of experiments made upon potassium perchlorate, $KClO_4$. In three experiments it was found that the salt was not quite free from chlorate, and in three more it contained traces of iron. A single determination upon very pure material gave 46.187 per cent of oxygen and 53.813 of residue.

In 1845 two series of experiments were published by Gerhardt.[1] The first, made in the usual way, gave these results:

60.871
60.881
60.875

Mean, 60.8757±.0020

In the second series the oxygen was passed through a weighed tube containing moist cotton, and another filled with pumice stone and sulphuric acid. Particles were this collected which in the earlier series escaped. From these experiments we get—

60.947
60.947
60.952

Mean, 60.9487±.0011

These last results were afterwards sharply criticised by Marignac,[2] who seriously questioned their value.

The next series, in order of time, is due to Maumené.[3] This chemist supposed that particles of chlorate, mechanically carried away, might continue to exist as chlorate, undecomposed; and hence that all previous series of experiments might give too high a value to the residual chloride. In his determinations, therefore, the ignition tube, after expulsion of the oxygen, was uniformly heated in all its parts. Here are his percentages of residue:

60.788	60.785
60.790	60.795
60.793	60.795
60.791	

Mean, 60.791±.0009

The question which most naturally arises in connection with these results is, whether portions of chloride may not have been volatilized, and so lost.

Closely following Maumené's paper, there is a short note by Faget,[4] giving certain mean results. According to this chemist, when potassium chlorate is ignited slowly, we get 60.847 per cent of residue. When the ignition is rapid, we get 60.942. As no detailed experiments are given, these figures can have no part in our discussion.

Next in order are two series of analyses by Stas.[5] In the first series are the results obtained by igniting the chlorate. In the second series the chlorate was reduced by strong hydrochloric acid, after the method followed by Penny:

First series.	*Second series.*
60.8380	60.850
60.8395	60.853
60.8440	60.844
60.8473	
60.8450	Mean, 60.849±.0017
Mean, 60.84276±0.0012	

[1] Compt. Rend., 21, 1280.
[2] Suppl. Biblio. Univ. Geneve, Vol. 1.
[3] Ann. Chim. Phys. (3), 18, 71. 1846.
[4] Ann. Chim. Phys. (3), 18, 80. 1846.
[5] Oeuvres Complètes, 1, 395–405.

In these experiments very elaborate precautions were taken to avoid error and insure accuracy. All weighings were reduced to a vacuum standard, from 70 to 142 grammes of chlorate were used in each experiment, and the chlorine carried away with the oxygen in the first series was absorbed by finely divided silver and estimated.

These determinations by Stas were generally regarded as conclusive until 1911, when Staehler and Meyer[1] published their analyses of potassium chlorate. Their material was purified with scrupulous care and analyzed by a method similar to that employed by Stas in his second series of analyses but somewhat modified. The chlorate, after heating to fusion in a quartz glass vessel in order to secure complete dehydration, was dissolved in water and then reduced to chloride by a stream of pure gaseous hydrochloric acid. The potassium chloride was afterwards fused in an atmosphere of nitrogen in order to remove all traces of water and acid. Two sets of analyses with vacuum weights are reported by Staehler and Meyer; one preliminay, the other final. The data for the preliminary series, with percentages calculated by myself, are as follows:

$KClO_3$.	KCl.	Per cent KCl.
12.38248	7.53218	60.829
11.28213	6.86340	60.834
14.22480	8.65366	60.835
11.52268	7.00963	60.833
12.44913	7.57331	60.834
		Mean, 60.833±.0007

For the final series the figures are—

$KClO_3$.	KCl.	Per cent KCl.
10.26355	6.24370	60.8337
10.08261	6.13362	60.8337
10.03177	6.10269	60.8337
10.63651	6.47073	60.8351
12.05095	7.33096	60.8351
		Mean, 60.8339±.00022

The several series of analyses of potassium chlorate now combine as follows:

Berzelius	60.851 ±.0006
Penny	60.8225±.0014
Pelouze	60.843 ±.0053
Marignac	60.8392±.0013
Gerhardt, first	60.8757±.0020
Gerhardt, second	60.9487±.0011
Maumené	60.791 ±.0009
Stas, first	60.8428±.0012
Stas, second	60.849 ±.0017
Staehler and Meyer, first	60.833 ±.0007
Staehler and Meyer, second	60.8339±.00022
General mean	60.8365±.00018

Hence if O=16, KCl=74.5631±.0004.

Guye and Ter Gazarian[2] have called attention to the fact that potassium chlorate tends to retain some chloride as an impurity. Staehler and Meyer, however, claim to have avoided that source of error in their analyses. The correction for such an impurity probably applies to the earlier analyses of the chlorate.

The percentage of oxygen in sodium chlorate has been determined only by Penny,[3] who used the same method which he applied to the potassium salt. Four experiments gave the following results:

45.060	45.080
45.075	45.067
Mean, 45.0705±.0029	

Hence NaCl=54.500±.0048.

[1] Zeitsch. anorg. Chem., 71, 378. 1911. For a criticism by Guye, see Journ. Chim. Phys., 10, 145, and a reply by Meyer and Staehler, in Zeitsch. anorg. Chem., 77, 255.

[2] Compt. Rend., 143, 411. According to Guareschi the bromate is also a constant impurity in the chlorate and also in the iodate. See Chem. Zentralblatt, 84, 978. 1913.

[3] Phil. Trans. 1839, p. 25.

For the composition of silver chlorate there are analyses by Marignac [1] and by Stas.[2] Marignac's series is as follows:

$AgClO_3$.	*AgCl.*	*Per cent, AgCl.*
24. 540	18. 363	74. 920
25. 809	19. 336	74. 913
30. 306	22. 709	74. 932
28. 358	21. 247	74. 924
28. 287	21. 185	74. 893
57. 170	42. 840	74. 934
		Mean, 74. 9193±. 0041

Corrected to a vacuum, this becomes 74.917.

The determinations by Stas are only two in number, giving the subjoined percentages of AgCl in $AgClO_3$:

74. 919
74. 922
Mean, 74. 9205±. 0010

Combining this with Marignac's figure, the general mean becomes 74.9203 ± .0010. Hence AgCl = 143.390 ± .0060.

ANALYSES OF BROMATES AND IODATES.

Accurate analyses of bromates and iodates, available for atomic weight determinations, are few in number, and from a modern point of view, not satisfactory. Potassium bromate was analyzed by Marignac,[3] by careful calcination, with all the precautions taken to avoid loss. His figures are subjoined:

$KBrO_3$.	*KBr.*	*Per cent O.*
6. 801	4. 849	28. 7016
3. 480	2. 483	28. 6494
6. 320	4. 506	28. 7025
23. 186	16. 521	28. 7458
		Mean, 28. 6998±. 0133

Hence KBr = 119.249 ± .0596.

Marignac attempted to analyze silver bromate, but found difficulties in drying the salt. He also made some experiments upon the precipitation of silver bromate by potassium chloride, but published no details of his determinations. He merely states that from 31.32 to 31.47 parts of KCl were needed to precipitate the silver from 100 parts of bromate.

Stas [4] effected the analysis of silver bromate by reduction with sulphurous acid, its content in water having been previously determined. After applying all corrections the subjoined percentages of oxygen were found from the weight of the bromate and that of the residual silver bromide:

20. 351
20. 347
Mean, 20. 349±. 0014

Hence AgBr = 187.884 ± .0133.

The percentage of oxygen in potassium iodate has been determined by Millon.[5] In three experiments he found:

22. 46
22. 49
22. 47
Mean, 22. 473±. 005

Hence KI = 165.590 ± .0384.

According to Marignac [6] potassium iodate loses iodine when calcined, and is therefore unsuited to atomic weight determinations.

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[1] Oeuvres Complètes, 1, 80.
[2] Oeuvres Complètes, 1, 685.
[3] Oeuvres Complètes, 1, 84.
[4] Oeuvres Complètes, 1, 635.
[5] Ann. Chim. Phys. (3), 9, 400. 1843.
[6] Oeuvres Complètes, 1, 85.

Millon also estimated the oxygen in silver iodate, getting the following percentages:

17. 05
17. 03
17. 06

Mean, 17. 047 ± .005

The analysis of silver iodate has also been performed with extreme care by Stas.[1] From 76 to 157 grammes were used in each experiment, the weights being reduced to a vacuum. As the salt could not be prepared in an absolutely anhydrous condition, the water expelled in each analysis was accurately estimated and the necessary corrections applied. In two of the experiments the iodate was decomposed by heat, and the oxygen given off was fixed upon a weighed quantity of copper heated to redness. Thus the actual weights, both of the oxygen and the residual iodide, were obtained. In a third experiment the iodate was reduced to iodide by a solution of sulphurous acid, and the oxygen was estimated only by difference. In the three percentages of oxygen given below, the result of this analysis comes last. The figures for oxygen are as follows:

16. 976
16. 972
16. 9761

Mean, 16. 9747 ± .0009

This, combined with Millon's series above cited, gives us a general mean of 16.9771 ± .0009. Hence AgI = 234.734 ± .0126.

THE SILVER-CHLORINE RATIO.

For the ratio between silver and chlorine there are many series of determinations, some direct and some indirect. As with numerous other ratios, the first work entitled to any consideration was done by Berzelius.[2]

He made three estimations, using each time 20 grammes of pure silver. This was dissolved in nitric acid. In the first experiment the silver chloride was precipitated and collected on a filter. In the second and third experiments the solution was mixed with hydrochloric acid in a flask, evaporated to dryness, and the residue then fused and weighed without transfer. One hundred parts of silver formed of chloride:

132. 700
132. 780
132. 790

Mean, 132. 757 ± .019

Turner's work [3] closely resembles that of Berzelius. Silver was dissolved in nitric acid and precipitated as chloride. In experiments one, two and three the mixture was evaporated and the residue fused. In experiment four the chloride was collected on a filter. A fifth experiment was made, but has been rejected as worthless.

The results were as follows: In a third column I put the quantity of AgCl proportional to 100 parts of Ag.

Ag.	*AgCl.*	*Ratio.*
28. 407	37. 737	132. 844
41. 917	55. 678	132. 829
40. 006	53. 143	132. 837
30. 922	41. 070	132. 818

Mean, 132. 832 ± .0038

The same general method of dissolving silver in nitric acid, precipitating, evaporating, and fusing without transfer of material was also adopted by Penny.[4] His results for 100 parts of silver are as follows, in parts of chloride:

[1] Oeuvres Complètes, 1, 628. [2] Thomson's Annals of Philosophy, 15, 89. 1820. [3] Phil. Trans., 1829, 291. [4] Phil. Trans., 1839, 28.

132. 836	132. 840
132. 840	132. 830
132. 830	132. 838
143. 840	

Mean, 132. 8363±.0012

In 1842 Marignac [1] found that 100 parts of silver formed 132.74 of chloride, but gave no available details. Later,[2] in another series of determinations, he was more explicit. Silver was dissolved in nitric acid, and precipitated by hydrochloric acid. The precipitate was washed several times with boiling water, by decantation, and the chloride was finally dried and fused in the same flask in which it had been formed. The figures are as follows:

Ag.	*AgCl.*	*Ratio.*
79. 853	106. 080	132. 844
69. 905	92. 864	132. 843
64. 905	86. 210	132. 825
92. 362	122. 693	132. 839
99. 653	132. 383	132. 844

Mean, 132. 839±.0024

Corrected for weighing in air the mean becomes 132.854.

The above series all represent the synthesis of silver chloride. Maumené [3] made analyses of the compound, reducing it to metal in a current of hydrogen. His experiments make 100 parts of silver equivalent to chloride:

132. 734	132. 729
132. 754	132. 741
132. 724	

Mean, 132.7364±.0077

By Dumas [4] we have the following estimations:

Ag.	*AgCl.*	*Ratio.*
9. 954	13. 227	132. 882
19. 976	26. 542	132. 869

Mean, 132. 8755±.0044

Next in order are seven determinations by Stas.[5] In the first, second, and third, silver was heated in chlorine gas, and the synthesis of silver chloride thus effected directly. In the fourth and fifth silver was dissolved in nitric acid, and the the chloride thrown down by passing hydrochloric acid gas over the surface of the solution. The whole was then evaporated in the same vessel, and the chloride fused, first in an atmosphere of hydrochloric acid, and then in a stream of air. The sixth synthesis was similar to these, only the nitric solution was precipitated by hydrochloric acid in slight excess, and the chloride thrown down was washed by repeated decantation. All the decanted liquids were afterwards evaporated to dryness, and the trace of chloride thus recovered was estimated in addition to the main mass. The latter was fused in an atmosphere of HCl. The seventh experiment was like the sixth, only ammonium chloride was used instead of hydrochloric acid. From 98.3 to 399.7 grammes of silver were used in each experiment, the operations were performed chiefly in the dark, and all weighings were reduced to a vacuum. In every case the chloride obtained was beautifully white. Treating Stas' determinations as a single series, his figures are as follows:

Ag.	*AgCl.*	*Ratio.*
91. 462	121. 4993	132. 841
69. 86735	92. 8145	132. 843
101. 519	134. 861	132. 843
108. 549	144. 207	132. 849
399. 651	530. 920	132. 846
99. 9925	132. 8382	132. 848
98. 3140	130. 602	132. 8417

Mean, 132. 8445±. 0008

[1] Ann. Chem. Pharm., 44, 21.
[2] Oeuvres Complètes, 1, 79.
[3] Ann. Chim. Phys. (3), 18, 49. 1846.
[4] Ann .Chem. Pharm., 113, 21. 1860.
[5] Oeuvres Complètes, 1, 333–341.

According to Richards and Wells,[1] who made two very careful series of syntheses, the work of Stas on the silver-chlorine ratio was subject to constant errors. His silver probably contained occluded oxygen, and perhaps alkalies also, and his glass vessels were attacked and changed in weight by the acids used in his operations. These errors were avoided by Richards and Wells, who precipitated and fused their silver chloride either in porcelain or quartz vessels, generally the latter, and who employed silver of the highest possible purity. A number of minute corrections were also applied to their determinations, but these can not be considered in detail now. The results obtained appear in the two following tables:

Preliminary Series.

Ag.	*AgCl.*	*Ratio.*
9.06843	12.04365	132.861
8.39217	11.14985	132.860
5.37429	7.14056	132.865
8.08222	10.73869	132.868
7.08517	9.41362	132.864
7.97715	10.59837	132.859
8.11978	10.78767	132.857
8.53452	11.33907	132.861
6.73284	8.94511	132.858
8.91366	11.84240	132.857
9.72295	12.91769	132.858
8.63961	11.47862	132.860
11.13795	14.79849	132.865
		Mean, 132.8610±.00065

Final Series.

Ag.	*AgCl.*	*Ratio.*
7.24427	9.62508	132.865
8.30502	11.03484	132.870
7.29058	9.68676	132.867
8.58472	11.40614	132.866
8.01318	11.64648	132.862
9.77160	12.98335	132.868
7.98170	10.60528	132.870
11.49983	15.27964	132.868
6.25318	8.30834	132.866
7.72479	12.26360	132.866
		Mean, 132.8668±.0005

Five more determinations of this ratio, by Richards and Anderegg [2] remain to be noted. The usual Harvard methods of operation were employed. The figures are given in two distinct groups, which are consolidated here.

Ag.	*AgCl.*	*Ratio.*
6.22211	8.26738	132.871
5.16568	6.86361	132.869
5.18476	6.88876	132.866
5.92279	7.86933	132.864
5.00706	6.65256	132.864
		Mean, 132.867±.0009

The foregoing ten series of determinations are to be classed as *direct;* that is, they were made for the express purpose of measuring the ratio between silver and chlorine, and were not complicated by other considerations. Arranged in the order of ascending magnitude, and expressed in the form Ag : Cl : : 100 : x, these combine as follows:

[1] Publ. Carnegie Inst., Washington, No. 28, 1905.

[2] Journ. Amer. Chem. Soc., 37, 14–21, 1915.

Maumené	32.736 ±.0077
Berzelius	32.757 ±.0190
Turner	32.832 ±.0038
Penny	32.836 ±.0012
Stas	32.8445 ±.0008
Marignac	32.854 ±.0024
Richards and Wells, preliminary	32.861 ±.00065
Richards and Wells, final	32.8668±.0005
Richards and Anderegg	32.867 ±.0009
Dumas	32.8755±.0044
General mean	32.8670±.00038

This general mean is almost identical with Richards and Wells' final determination.

A second group of determinations of the silver-chlorine ratio may be termed *incidental.* A chloride is balanced against silver, and the silver chloride produced is also weighed, and this procedure, intended to fix other atomic weights, also gives values for the ratio now under consideration. The following determinations, thus obtained, are all useful. I limit myself, however, to work done by individual authorities, and do not attempt to combine observations, say of RCl : Ag by one chemist, and RCl : AgCl by another, into determinations of the ratio Ag : AgCl. The details of the several investigations will be found in subsequent chapters of this work, in relation to what I may term the several collateral elements.

The first series of this incidental kind to be now considered is due to Lenher,[1] and is derived from his data on the atomic weight of selenium. Silver selenite was converted into silver chloride, and the latter was afterwards reduced to metal by heating in hydrogen. The vacuum weights and the derived ratio appear in the next table.

AgCl.	*Ag.*	*Ratio.*
.21897	.16480	132.870
.48522	.36534	132.813
.58999	.44417	132.830
.67532	.50821	132.882
.82232	.61882	132.885
1.08350	.81562	132.844
1.36288	1.02588	132.850
1.67234	1.25884	132.848
		Mean, 132.853±.0060

Similar data are furnished by Ebaugh's[2] analyses of silver arsenate, which were designed to determine the atomic weight of arsenic. The weights are all reduced to a vacuum.

AgCl.	*Ag.*	*Ratio.*
.21547	.162175	132.863
.44615	.33583	132.850
.48820	.367525	132.844
.74517	.56099	132.831
.88083	.66318	132.819
.94830	.71400	132.815
.98014	.73771	132.863
		Mean, 132.841±.0050

In their memoir upon the atomic weight of cæsium, Richards and Archibald[3] give analyses of cæsium and potassium chloride, balancing each salt against silver and silver chloride. In the following table the first two determinations are derived from the potassium salt, and the others from the cæsium compound. The weights refer to the vacuum standard, as do all the others in this group of determinations.

[1] Journ. Amer. Chem. Soc., 20, 555. 1898. [2] Doctoral thesis, University of Pennsylvania, 1901. [3] Proc. Amer. Acad., 38, 443. 1903.

Ag.	*AgCl.*	*Ratio.*
3.61747	4.80600	132.855
3.62283	4.81325	132.859
2.45600	3.26240	132.834
2.53351	3.36532	132.832
1.45686	1.93555	132.858
1.94244	2.58003	132.824
2.05023	2.72382	132.854
1.50720	2.00253	132.864
1.32251	1.75678	132.837
1.29434	1.71972	132.864
1.13743	1.51093	132.837
1.97590	2.62484	132.835
2.00760	2.66720	132.855
3.24850	4.31570	132.852
		Mean, 132.847±.0024

Figures of the same order are given by Archibald in his research upon the atomic weight of rubidium,[1] and again in his memoir upon potassium.[2]

Rubidium Series.

Ag.	*AgCl.*	*Ratio.*
1.78454	2.37070	132.842
1.84241	2.44778	132.858
2.04710	2.71960	132.851
.97702	1.29796	132.849
1.91316	2.54118	132.826
2.58550	3.43475	132.847
1.96076	2.60452	132.832
1.91462	2.54386	132.865
1.89346	2.51557	132.856
2.01515	2.67685	132.836
1.94594	2.58528	132.855
2.07668	2.75878	132.846
3.56998	4.74233	132.842
2.17233	2.88613	132.862
		Mean, 132.848±.0020

Potassium Series.

Ag.	*AgCl.*	*Ratio.*
3.20598	4.25916	132.850
2.88479	3.83250	132.852
4.19557	5.57396	132.853
6.85280	9.10362	132.845
		Mean, 132.850±.0012

The analyses of cobalt chloride, by Baxter and Coffin,[3] furnish the subjoined figures:

Ag.	*AgCl.*	*Ratio.*
1.82671	2.42676	132.846
2.45398	3.26095	132.884
6.38081	8.47735	132.857
4.92244	6.54019	132.865
5.78815	7.69084	132.872
5.47410	7.27284	132.859
2.61905	3.48012	132.877
		Mean, 132.8657±.0034

[1] Journ. Chem. Soc., 85, 786. 1904. [2] Trans. Roy. Soc., Canada, 1904, Sec. III, p. 47. [3] Zeitsch. anorg. Chem., 51, 171. 1906.

From the analyses, by Baxter and Hines,[1] of manganese chloride we have—

Ag.	*AgCl.*	*Ratio.*
7.93740	10.54641	132.870
6.05041	8.03868	132.862
5.67279	7.53731	132.868
6.11818	8.12932	132.871
5.91637	7.86129	132.873
7.67995	10.20372	132.862
6.72227	8.93140	132.863

Mean, 132.8670±.0012

Baxter and Wilson,[2] analyzing lead chloride, obtained the following data:

Ag.	*AgCl.*	*Ratio.*
3.62987	4.82273	132.862
3.21408	4.27016	132.858
3.97568	5.28272	132.876
2.99456	3.97949	132.891
2.40837	3.19909	132.832
3.33407	4.42982	132.865

Mean, 132.864±.0054

By Hönigschmid[3] there are two determinations, based upon his study of radium chloride. They are—

Ag.	*AgCl.*	*Ratio.*
0.71630	0.95166	132.858
.70600	.93804	132.867

Mean, 132.8625±.0030

Baxter and Moore,[4] in their work on the atomic weight of phosphorus, give the following figures:

Ag.	*AgCl.*	*Ratio.*
10.82441	14.38118	132.858
10.36771	13.77434	132.858
13.46408	17.88933	132.860
12.21814	16.23430	132.870
12.14555	16.13727	132.884
12.08725	16.05962	132.874
11.43585	15.19245	132.849
8.45324	11.23091	132.859
13.94377	18.52592	132.862

Mean, 132.864 ± 0.0030

From Scheuer's[5] analyses of silver sulphate we have—

Ag.	*AgCl.*	*Ratio.*
8.63592	11.47436	132.868
5.99316	7.46296	132.868
10.21124	13.56757	132.869
8.96085	11.90590	132.866
9.70232	12.89159	132.871

Mean, 132.8684 ± 0.0005

Richards and Lembert[6] in their determinations on the atomic weight of lead from uraninite give the following figures:

Ag.	*AgCl.*	*Ratio.*
3.00984	3.99877	132.857
4.33300	5.75707	132.866

[1] Journ. Amer. Chem. Soc., 28, 1560. 1906.
[2] Journ. Amer. Chem. Soc., 30, 187, 1908.
[3] Monatsh. Chem., 33, 253.
[4] Journ. Amer. Chem. Soc., 34, 1644.
[5] Arch. Sci. Phys. Nat. (4), 36, 318.
[6] Journ. Amer. Chem. Soc., 36, 1329.

Ag.	*AgCl.*	*Ratio.*
4.27157	5.67573	132.872
3.01600	4.00703	132.859
3.14788	4.18265	132.872
2.18162	2.89816	132.844
2.29951	3.06475	132.844
3.15153	4.18670	132.846
1.56952	2.08663	132.847
		Mean, 132.868 ± 0.0038

Hönigschmid and Horovitz[1] determined the atomic weight of isotopic lead ("uranblei") and give two series of figures:

First series.

Ag.	*AgCl.*	*Ratio.*
2.52563	3.35537	132.855
3.07636	4.08686	132.847
2.94693	3.91519	132.856
2.87400	3.81830	132.856
3.50343	4.65464	132.859
		Mean, 132.855 ± 0.0014

Second series.

Ag.	*AgCl.*	*Ratio.*
3.76724	5.00512	132.857
3.09903	4.11741	132.853
3.82647	5.08425	132.870
		Mean, 132.863 ± 0.0026

In another paper the same chemists[2] give a series of determinations based upon analyses of ordinary lead. The figures for silver and silver chloride are as follows:

Ag.	*AgCl.*	*Ratio.*
4.79374	6.36895	132.860
3.68659	4.89837	132.870
3.75047	4.98328	132.871
		Mean, 132.867 ± 0.0030

A long series of determinations by Baxter, Whitcomb, and Stewart[3] is derived from their analyses of neodymium chloride. Two aberrant determinations are rejected by the authors and are therefore omitted here. The figures for the present ratio are as follows:

Ag.	*AgCl.*	*Ratio.*
5.21445	6.92786	132.859
5.78760	7.69005	132.871
4.84458	6.43738	132.878
7.75892	10.30876	132.863
6.41045	8.51634	132.851
5.36392	7.12743	132.877
7.14338	9.49134	132.868
6.12054	8.13232	132.868
5.45444	7.24714	132.867
7.66088	10.17891	132.868
7.23524	9.61299	132.863
9.33359	12.40098	132.864
5.81558	7.72718	132.870
		Mean, 132.867 ± 0.0013

[1] Monatsh. Chem., 36, 355. [2] Monatsh. Chem., 36, 375. [3] Journ. Amer. Chem. Soc., 38, 302.

These incidental series of values for the ratio Ag : Cl :: 100 : x now combine as follows:

Ebaugh, As series	32.841 ±.0050
Richards and Archibald, Cs series	32.847, ±.0024
Archibald, Rb series	32.848, ±.0020
Archibald, K series	32.850, ±.0012
Lenher, Se series	32.853, ±.0060
Hönigschmid and Horovitz, Pb series 1	32.855, ±.0014
Hönigschmid, Ra series	32.8625, ±.0030
Hönigschmid and Horovitz, Pb series 2	32.863, ±.0026
Baxter and Wilson, Pb series	32.864, ±.0054
Baxter and Moore, P series	32.864, ±.0030
Baxter and Coffin, Co series	32.8657, ±.0034
Baxter and Hines, Mn series	32.867, ±.0012
Baxter, Whitcomb and Stewart, Nd series	32.867, ±.0013
Hönigschmid and Horovitz, Pb series 3	32.867, ±.0030
Richards and Lembert, Pb series	32.868, ±.0038
Scheuer, Ag_2SO_4 series	32.8684, ±.0005
General mean	32.8640±.00036

A third group of determinations is to be classed as *indirect.* When two ratios, RCl : Ag and RCl : AgCl have been measured by the same investigator, but independently of each other, the cross ratio, Ag : Cl :: 100 : x is easily calculable from them. The examples to be given presently are almost self-explanatory; but the details of the determinations must be sought for in the later sections of this work, on titanium, magnesium, barium, cadmium, etc.

In his determinations of the atomic weight of titanium, Thorpe gives data from which the subjoined ratios are derived:

$$4Ag:TiCl_4::100:43.999\pm.0032$$
$$4AgCl:TiCl_4::100:33.118\pm.0019$$

Hence Ag : Cl : : 100 : 32.855 ±.0092.

From Richards's analyses of barium chloride we have—

$$2Ag : BaCl_2 :: 100 : 96.525\pm.0010$$
$$2AgCl : BaCl_2 :: 100 : 72.653\pm.0014$$

Hence Ag : Cl : : 100 : 32.8575 ±.0029.

Ratios computed from the analyses of magnesium chloride by Richards and Parker:

$$2Ag : MgCl_2 :: 100 : 44.138\pm.0003$$
$$2AgCl : MgCl_2 :: 100 : 33.226\pm.0013$$

Hence Ag : Cl : : 100 : 32.842 ±.0054.

Data for cadmium chloride are given by Baxter and Hines, and also, later, by Baxter, Hines and Frevert. Their series, combined together, give—

$$2Ag : CdCl_2 :: 100 : 84.9677\pm.0008$$
$$2AgCl : CdCl_2 :: 100 : 63.9523\pm.0004$$

Hence Ag : Cl : : 100 : 32.861 ±.0016.

For sodium chloride the analyses of Richards and Wells give the following ratios:

$$Ag : NaCl :: 100 : 54.1854\pm.00015$$
$$AgCl : NaCl :: 100 : 40.7797\pm.00028$$

Hence Ag : Cl : : 100 : 32.873 ±.0010.

The potassium chloride ratios of Richards and Staehler are—

$$Ag : KCl :: 100 : 69.1073\pm.00032$$
$$AgCl : KCl :: 100 : 52.0118\pm.00025$$

Hence Ag : Cl : : 100 : 32.869 ±.0009.

In Archibald's work on the atomic weight of platinum the subjoined ratios appear:

$$Ag : Pt :: 100 : 180.965 \pm .0034$$
$$AgCl : Pt :: 100 : 136.203 \pm .0031$$

Hence $Ag : Cl :: 100 : 32.864 \pm .0039$.

The determinations by Richards and Willard of the atomic weight of lithium gave two pairs of values for the silver-chlorine ratio.

Preliminary series.

$$Ag : LiCl :: 100 : 39.3023 \pm .00048$$
$$AgCl : LiCl :: 100 : 29.5802 \pm .00033$$

Hence $Ag : Cl :: 100 : 32.867 \pm .0022$.

Final series.

$$Ag : LiCl :: 100 : 39.2992 \pm .00014$$
$$AgCl : LiCl :: 100 : 29.5786 \pm .00014$$

Hence $Ag : Cl :: 100 : 32.8637 \pm .00077$

From the strontium chloride ratios of Thorpe and Francis we have—

$$2Ag : SrCl_2 :: 100 : 73.490 \pm .0008$$
$$2AgCl : SrCl_2 :: 100 : 55.311 \pm .0009$$

Hence $Ag : Cl :: 100 : 32.867 \pm .0026$.

Briscoe and Little give two ratios for vanadyl chloride, as follcws:

$$3Ag : VOCl_3 :: 100 : 53.554 \pm .0008$$
$$3AgCl : VOCl_3 :: 100 : 40.3085 \pm .0010$$

Hence $Ag : Cl :: 100 : .0062$.

Hönigschmid and Horovitz in their earlier study of isotopic lead give data yielding the following ratios:

$$2Ag : PbCl_2 :: 100 : 128.687 \pm .0021$$
$$2AgCl : PbCl_2 :: 100 : 96.854 \pm .0010$$

Hence $Ag : Cl :: 100 : 32.864 \pm .0026$.

The atomic weight detcrminations by Baxter and Grover for ordinary lead give these ratios:

$$2Ag : PbCl_2 :: 100 : 128.905 \pm .0010$$
$$2AgCl : PbCl_2 :: 100 : 97.021 \pm .0010$$

Hence $Ag : Cl :: 100 : 32.863 \pm .0017$.

For praseodymium Baxter and Stewart find—

$$3Ag : PrCl_3 :: 100 : 76.4090 \pm .0006$$
$$3AgCl : PrCl_3 :: 100 : 57.5100 \pm .0007$$

Hence $Ag : Cl :: 100 : 32.862 \pm .0019$.

Similar data by Baxtcr and Chapin are given for neodymium:

$$3Ag : NdCl_3 :: 100 : 77.4437 \pm .0009$$
$$3AgCl : NdCl_3 :: 100 : 58.2876 \pm .0006$$

Hence $Ag : Cl :: 100 : 32.865 \pm .0020$.

These indirect determinations now combine as follows:

Richards and Parker, Mg ratios	32.842 ±.0054
Thorpe, Ti ratios	32.855 ±.0092
Richards, Ba ratios	32.8575±.0029
Briscoe and Little, V ratios	32.860 ±.0062
Baxter, Hines and Frevert, Cd ratios	32.861 ±.0016
Baxter and Stewart, Pr ratios	32.862 ±.0019
Baxter and Grover, Pb ratios	32.863 ±.0017
Richards and Willard, 2d Li series	32.8637±.00077
Archibald, Pt ratios	32.864 ±.0039
Hönigschmid and Horovitz, Pb ratios	32.864 ±.0026
Baxter and Chapin, Nd ratios	32.865 ±.0020
Richards and Willard, 1st Li series	32.867 ±.0022
Thorpe and Francis, Sr ratios	32.867 ±.0026
Richards and Staehler, K ratios	32.869 ±.0009
Richards and Wells, Na ratios	32.873 ±.0010
General mean	32.8660±.00041

By combining the three groups of determinations, a final value for the ratio Ag:Cl::100:x is obtained, thus—

Direct determinations	32.867±.00038
Incidental determinations	32.864±.00036
Indirect determinations	32.866±.00041
General mean of 41 series	32.8656±.00022

THE SILVER-BROMINE RATIO.

The measurements of the silver-bromine ratio resemble those of the ratio between silver and chlorine, and fall into three groups. First in order are the *direct* determinations.

Marignac,[1] to effect the synthesis of silver bromide, dissolved the metal in nitric acid, precipitated the solution with potassium bromide, washed, dried, fused, and weighed the product. The ratio Ag: Br :: 100 : x is given in the third column:

Ag.	*AgBr.*	*Ratio.*
25.000	43.518	74.072
20.120	35.020	74.055
15.000	26.110	74.066
	Mean,	74.064 ±.003

Corrected for weighing in air the mean becomes 74.077.

Much more elaborate determinations of this ratio are due to Stas.[2] In one experiment a known weight of silver was converted into nitrate, and precipitated in the same vessel by pure hydrobromic acid. The resulting bromide was washed thoroughly, dried, and weighed. In four other estimations the silver was converted into sulphate. Then a known quantity of pure bromine, as nearly as possible the exact amount necessary to precipitate the silver, was transformed into hydrobromic acid. This was added to the dilute solution of the sulphate, and after precipitation was complete, the minute trace of an excess of silver in the clear supernatant fluid was determined. All weighings were reduced to a vacuum. The data are as follows:

Ag.	*AgBr.*	*Ratio.*
53.1958	92.6042	74.0830
51.3436	89.3780	74.0790
55.0615	95.8505	74.0795
55.8040	97.1450	74.0805
43.3620	84.1904	74.0830
	Mean,	74.0810 ± .0006

[1] Oeuvres Complètes, 1, 83.

[2] Oeuvres Complètes, 1, 587, 603.

In his paper on the atomic weight of cadmium,[1] Huntington gives three syntheses and three analyses of silver bromide. The data are as follows, with the usual ratio given in the last column:

Ag.	*AgBr.*	*Ratio.*
1. 4852	2. 5855	74. 084
1. 4080	2. 4510	74. 077
1. 4449	2. 5150	74. 060
AgBr.	*Ag.*	*Ratio.*
4. 1450	2. 3817	74. 035
1. 8172	1. 0437	74. 111
4. 9601	2. 8497	74. 057
		Mean, 74. 071±.0072

Similar synthetic data are also given by Richards, incidentally to his work on copper.[2] There are two sets of three experiments each, which can here be treated as one series, thus:

Ag.	*AgBr.*	*Ratio.*
1.11235	1.93630	74.073
1.57620	2.74335	74.044
2.16670	3.77170	74.076
.9664	1.68205	74.053
.9645	1.6789	74.069
.9639	1.6779	74.074
		Mean, 74.065±.0035

In their research upon the eletrochemical equivalents of copper and silver, Richards, Collins, and Heimrod [3] give the following syntheses of silver bromide from electrolytic silver:

Ag.	*AgBr.*	*Ratio.*
0.71585	1.24567	74.013
5.43807	9.46557	74.061
3.76993	6.56216	74.066
2.29649	3.99820	74.100
2.15701	3.75473	74.071
2.37893	4.14187	74.106
2.97120	5.17218	74.077
		Mean, 74.0706±.0078

It is only fair to state in this connection that the foregoing series was intended to determine the purity of the silver, and not as an accurate measure of the ratio.

Scott,[4] in his analyses of ammonium bromide, titrated the compound with silver. He afterwards collected and weighed the silver bromide, in order to determine the silver bromide ratio. The subjoined weights refer to the vacuum standard:

Ag.	*AgBr.*	*Ratio.*
6.82315	11.87733	74.074
9.66809	16.82816	74.090*
5.41906	9.43315	74.0735
5.51258	9.59596	74.074
5.70686	9.93346	74.062
5.33191	9.28093	74.064
5.62572	9.79254	74.067
		Mean, 74.072±.0023

[1] Proc. Amer. Acad., 17, 28. 1881.
[2] Proc. Amer. Acad., 25, 199, 210, 211. 1890.
[3] Proc. Amer. Acad., 35, 139. 1899.
[4] Journ. Chem. Soc., 79, 147. 1901.
* The starred figure is corrected for a trace of impurity.

In his paper on the atomic weight of iron Baxter [1] gives three direct comparisons of silver with silver bromide, with vacuum weights, as follows:

Ag.	*AgBr.*	*Ratio.*
4.77783	8.31754	74.086
5.87977	10.23533	74.077
4.82995	8.40809	74.082
		Mean, 74.082±.0018

A much more thorough and conclusive set of syntheses was published by Baxter [2] in 1906. The purest silver was dissolved in nitric acid, and precipitated by ammonium bromide. The silver bromide, before weighing, was fused in an atmosphere containing bromine vapor. With vacuum weights, Baxter's figures are as follows:

Ag.	*AgBr.*	*Ratio.*
4.71853	8.21363	74.072
5.01725	8.73393	74.078
5.96818	10.38932	74.079
5.62992	9.80039	74.077
8.13612	14.16334	74.080
5.07238	8.82997	74.079
4.80711	8.36827	74.081
4.27279	7.43776	74.072
5.86115	10.20299	74.078
7.91425	13.77736	74.083
6.40765	11.15468	74.084
6.38180	11.10930	74.078
6.23696	10.85722	74.079
9.18778	15.99392	74.078
8.01261	13.94826	74.079
10.48638	18.25452	74.078
8.59260	14.95797	74.079
8.97307	15.62022	74.079
		Mean, 74.0785±.00047

The direct determinations of the ratio Ag: Br combine thus:

Richards	74.065 ±.0035
Richards, Collins, and Heimrod	74.0706±.0078
Huntington	74.071 ±.0072
Scott	74.072 ±.0023
Marignac	74.077 ±.0030
Baxter, 1906	74.0785±.00047
Stas	74.081 ±.0006
Baxter, 1904	74.082 ±.0018
General mean	74.0797±.00035

Analyses of various metallic bromides have furnished many incidental determinations of the silver-bromine ratio, like those already described for silver and chlorine. In his work on titanium bromide, intended to determine the atomic weight of titanium, Thorpe [3] gives the following equivalent weights of silver and silver bromide:

Ag.	*AgBr.*	*Ratio.*
3.66122	6.375391	74.133
5.55097	9.663901	74.094
8.17645	14.227716	74.008
7.83493	13.639956	74.092
		Mean, 74.082±.0176

[1] Proc. Amer. Acad., 39, 250. 1904. [2] Journ. Amer. Chem. Soc., 28, 1322. 1906. [3] Journ. Chem. Soc., 47, 126. 1885.

Thorpe and Laurie [1] compared gold with silver and silver bromide, and gave equivalent weights as follows:

Ag.	*AgBr.*	*Ratio.*
3.38451	5.89199	74.087
2.60896	4.54261	74.113
2.28830	3.98288	74.054
2.26415	3.94309	74.153
1.97147	3.43015	73.989
2.01292	3.50207	73.980
2.50334	4.35736	74.062
2.93608	5.11045	74.057
		Mean, 74.062±.0143

In Richards' [2] memoir upon the atomic weight of barium, the subjoined vacuum weights of Ag and AgBr are given as equivalent to each other. Two additional determinations are rejected by Richards as inaccurate:

Ag.	*AgBr.*	*Ratio.*
1.71323	2.98230	74.075
2.13584	3.71809	74.081
1.52921	2.66191	74.071
2.11740	3.68615	74.089
1.72276	2.99868	74.063
1.34175	2.33530	74.049
4.11360	7.16120	74.086
2.56010	4.45670	74.083
2.51415	4.37669	74.082
		Mean, 74.075±.0029

From the analyses of nickel bromide, by Richards and Cushman,[3] the following figures are derived. These, and all the subsequent series, represent vacuum weights:

Ag.	*AgBr.*	*Ratio.*
3.23910	5.63892	74.089
2.66636	4.64208	74.098
3.33990	5.81391	74.074
1.31787	2.29435	74.088
1.23482	2.14963	74.085
1.30629	2.27384	74.069
2.21652	3.85805	74.059

Richards and Cushman also give one direct determination of the ratio, in which 2.10289 grammes of silver yielded 3.66066 of bromide. Ratio, 74.078. Including this in the foregoing series, the mean becomes 74.080 ± .0030.

Similar data appear in the memoirs of Richards and Baxter [4] on the atomic weight of cobalt. Their analyses of cobalt bromide gave the following equivalent figures:

Ag.	*AgBr.*	*Ratio.*
1.31702	2.29296	74.102
2.54585	4.43095	74.046
2.80449	4.88135	74.055
1.81170	3.15368	74.073
2.64879	4.61046	74.059
2.84891	4.95943	74.086
2.29593	3.99706	74.093
1.89033	3.29053	74.072

[1] Journ. Chem. Soc., 51, 565. 1887.
[2] Proc. Amer. Acad., 28, 1. 1893.
[3] Proc. Amer. Acad., 33, 97. 1897.
[4] Proc. Amer. Acad., 33, 115, 1897; and 34, 351, 1899.

There are also in these two memoirs by Richards and Baxter three direct determinations of the ratio, as follows:

Ag.	*AgBr.*	*Ratio.*
2.18679	3.80679	74.081
2.91386	5.07226	74.073
2.97097	5.17170	74.074

Taking these with the previous eight determinations as one series, the mean value for the ratio is $74.074 \pm .0033$.

From the analyses of uranium bromide, by Richards and Merigold,[1] the following figures are obtained:

Ag.	*AgBr.*	*Ratio.*
1.39365	2.42588	74.066
.82559	1.43713	74.073
1.43617	2.50009	74.080
		Mean, $74.073 \pm .0027$

The following figures are derived from the analyses, by Richards and Archibald,[2] of cæsium bromide:

Ag.	*AgBr.*	*Ratio.*
1.77402	3.08815	74.076
3.14606	5.47673	74.082
3.63740	6.33213	74.084
		Mean, $74.081 \pm .0017$

Archibald's [3] analyses of rubidium bromide give a similar series of comparisons, as follows:

Ag.	*AgBr.*	*Ratio.*
1.74930	3.04578	74.114
1.35230	2.35401	74.075
1.37061	2.38589	74.076
1.70300	2.96462	74.081
2.50590	4.36215	74.075
2.46502	4.29084	74.069
2.83340	4.93210	74.070
		Mean, $74.080 \pm .0040$

Baxter, Hines, and Frevert,[4] in order to determine the atomic weight of cadmium, analyzed cadmium bromide. Their silver figures are subjoined:

Ag.	*AgBr.*	*Ratio.*
9.08379	15.81319	74.081
5.40724	9.41267	74.075
5.35277	9.31830	74.084
5.61597	9.77649	74.088
4.07226	7.08933	74.088
4.63072	8.06130	74.083
4.68200	8.15070	74.086
4.75259	8.27360	74.086
		Mean, $74.084 \pm .0010$

[1] Proc. Amer. Acad., 37, 393. 1902.
[2] Proc. Amer. Acad., 38, 443. 1903.
[3] Journ. Chem. Soc., 85, 776. 1904.
[4] Journ. Amer. Chem. Soc., 28, 770. 1906.

Baxter and Hines[1] also analyzed manganese bromide, and gave the following equivalent weights of Ag and AgBr:

Ag.	*AgBr.*	*Ratio.*
6. 56765	11. 43300	74. 080
4. 83238	8. 41206	74. 077
4. 90354	8. 53642	74. 087
5. 65813	9. 85008	74. 087
5. 82600	10. 14206	74. 083
3. 61478	6. 29271	74. 083
5. 18711	9. 02959	74. 077
3. 94042	6. 85968	74. 085
4. 51250	7. 85571	74. 088
3. 61736	6. 29740	74. 088
4. 79620	8. 34915	74. 078
3. 59319	6. 25569	74. 098
5. 72641	9. 96840	74. 078
		Mean, 74. 084±.0011

Baxter and Thorvaldson[2] in their analyses of ferrous bromide derived from meteoric iron give the following weights for silver and silver bromide:

Ag.	*AgBr.*	*Ratio.*
3. 95631	6. 88720	74. 081
4. 67177	8. 13282	74. 084
4. 75550	8. 27855	74. 083
6. 95854	12. 11329	74. 078
3. 20904	5. 58632	74. 081
		Mean, 74. 081±.0008

From the figures relative to lead bromide the same chemists[3] give the following data:

Ag.	*AgBr.*	*Ratio.*
3. 85610	6. 71241	74. 073
3. 95874	6. 89124	74. 077
2. 94968	5. 13400	74. 062
4. 53498	7. 89526	74. 067
4. 12154	7. 17470	74. 078
4. 06484	7. 07672	74. 096
		Mean, 74. 075±.0032

Lead bromide was also analyzed by Baxter and Grover,[4] whose data give the following ratios:

Ag.	*AgBr.*	*Ratio.*
2. 38398	4. 15017	74. 086
2. 02288	3. 52224	74. 119
3. 04158	5. 29498	74. 086
3. 26022	3. 93446	74. 074
2. 53086	4. 40616	74. 097
2. 66549	4. 64048	74. 095
3. 40044	5. 91976	74. 088
2. 86337	4. 98467	74. 084
3. 69447	6. 43124	74. 077
2. 79011	4. 85708	74. 082
4. 01148	6. 98380	74. 095
		Mean, 74. 089±.0025

[1] Journ. Amer. Chem. Soc., 28, 1560. 1906.
[2] Journ. Amer. Chem. Soc., 33, 337. 1911.
[3] Journ. Amer. Chem. Soc., 37, 1020. 1915.
[4] Journ. Amer. Chem. Soc., 37, 1027. 1915.

Baxter, Moore, and Boylston[1] determined the atomic weight of phosphorus by analyses of the tribromide. Their data relative to the present ratio are as follows:

Ag.	*AgBr.*	*Ratio.*
7. 11504	12. 38560	74. 076
5. 63022	9. 80058	74. 071
5. 64583	9. 82830	74. 081
7. 74048	13. 47428	74. 075
5. 52140	9. 61143	74. 076
4. 58163	7. 97563	74. 079
5. 64835	9. 83261	74. 087
3. 84649	6. 69553	74. 073
6. 90379	12. 01761	74. 073
6. 59456	11. 47946	74. 075
9. 49930	16. 53569	74. 073
5. 15074	8. 96595	74. 071
5. 25447	9. 14663	74. 070
8. 45957	14. 72642	74. 080
5. 01851	8. 73586	74. 073
8. 68405	15. 11725	74. 081
9. 26406	16. 12737	74. 085
		Mean, 74. 076±.0008

Hönigschmid and Horovitz[2] determined the atomic weight of uranium by two series of analyses of the bromide. Their work furnishes the following data:

Series 1.

Ag.	*AgBr.*	*Ratio.*
3. 60418	6. 27409	74. 078
3. 09028	5. 37994	74. 092
3. 55214	6. 18353	74. 079
3. 42969	5. 97038	74. 079
		Mean, 74. 082±.0011

Series 2.

Ag.	*AgBr.*	*Ratio.*
4. 08466	7. 11092	74. 088
4. 14755	7. 22023	74. 086
4. 56818	7. 95237	74. 084
2. 42929	4. 22884	74. 077
3. 40682	5. 93036	74. 073
		Mean, 74. 082±.0019

The work of Hönigschmid[3] on thorium bromide yields the following data for the silver bromine ratio:

Ag.	*AgBr.*	*Ratio.*
4. 00046	6. 96402	74. 081
3. 01126	5. 24210	74. 083
3. 82643	6. 66091	74. 072
3. 67975	6. 40573	74. 080
4. 01057	6. 98157	74. 079
3. 27425	5. 69982	74. 080
2. 86343	4. 98479	74. 085
2. 92948	5. 09931	74. 069
3. 49762	6. 08888	74. 086
3. 92861	6. 83873	74. 075
4. 18375	7. 28310	74. 081
3. 38105	5. 88552	74. 074
		Mean, 74. 079±. 0010

[1] Proc. Amer. Acad., 47, 585. 1912.
[2] Monatsch. Chem., 37, 185. 1916.
[3] Zeitsch. Electrochem., 22, 18. 1916. From abstract by Baxter in Journ. Amer. Chem. Soc., 39, 340.

The incidental determinations of the ratio Ag : Br : : 100 : x now combine as follows:

Thorpe and Laurie, Au series	74.062 ±.0143
Richards and Merigold, U series	74.073 ±.0027
Richards and Baxter, Co series	74.074 ±.0033
Richards, Ba series	74.075 ±.0029
Baxter and Thorvaldson, Pb series	74.075 ±.0032
Baxter, Moore and Boylston, P series	74.076 ±.0008
Hönigschmid, Th series	74.079 ±.0010
Richards and Cushman, Ni series	74.080 ±.0030
Archibald, Rb series	74.080 ±.0040
Richards and Archibald, Cs series	74.081 ±.0017
Baxter and Thorvaldson, Fe series	74.081 +.0008
Thorpe, Ti series	74.082 ±.0176
Hönigschmid and Horovitz, U series 1	74.082 ±.0011
Hönigschmid and Horovitz, U series 2	74.082 ±.0019
Baxter, Hines, and Frevert, Cd series	74.084 ±.0010
Baxter and Hines, Mn series	74.084 ±.0011
Baxter and Grover, Pb series	74.089 ±.0025
General mean	74.0803±.00035

Several indirect determinations of the silver bromine ratio, as in the case of the chlorides, are deducible from analyses of metallic bromides. [1]

In Cooke's determinations of the atomic weight of antimony, the ratios are as follows:

$$3Ag : SbBr_3 :: 100 : 111.114 \pm .0014$$
$$3AgBr : SbBr_3 :: 100 : 63.830 \pm .008$$

Hence Ag : Br : : 100 : 74.078 ± .0219.

From Huntington's analyses of cadmium bromide we have—

$$2Ag : CdBr_2 :: 100 : 126.076 \pm .0052$$
$$2AgBr : CdBr_2 :: 100 : 72.4216 \pm .0028$$

Hence Ag : Br : : 100 : 74.086 + .0098.

The work of Richards on strontium bromide gives—

$$2Ag : SrBr_2 :: 100 : 114.689 \pm .0012$$
$$2AgBr : SrBr_2 :: 100 : 65.884 \pm .0006$$

Hence Ag : Br : : 100 : 74.077 ± .0024.

The ratios deduced from analyses of zinc bromide by Richards and Rogers are—

$$2Ag : ZnBr_2 :: 100 : 104.380 \pm .0007$$
$$2Ag : Br_2 :: 100 : 59.962 \pm .0004$$

Hence Ag : Br : : 100 : 74.077 ± .0016.

Analyses by Baxter of ferrous bromide yield the following ratios:

$$2Ag : FeBr_2 :: 100 : 99.960 \pm .0027$$
$$2AgBr : FeBr_2 :: 100 : 57.4195 \pm .00044$$

Hence Ag : Br : : 100 : 74.087 ± .0049.

Richards and Mueller studied potassium bromide with the subjoined results:

$$Ag : KBr :: 100 : 110.319 \pm .0004$$
$$AgBr : KBr :: 100 : 63.3727 \pm .0003$$

Hence Ag : Br : : 100 : 74.981 ± .0012.

The determinations by Archibald of the atomic weight of platinum give the following ratios:

$$Ag : Pt :: 100 : 180.965 \pm .0034$$
$$AgBr : Pt :: 100 : 103.955 \pm .0037$$

Hence Ag : Br :: 100 : 74.080 ± .0070.

[1] For details, see later sections of this work, on Sb, Cd, Sr, Zn, Cd, Fe, etc.

From the work of Thorpe and Francis on strontium bromide we have—

$$2Ag : SrBr_2 :: 100 : 114.703 \pm .0040$$
$$2AgBr : SrBr_2 :: 100 : 65.892 \pm .0011$$

Hence Ag : Br : : 100 : 74.077 ± .0067.

The determinations of the atomic weight of calcium by Richards and Hönigschmid yield the following ratios:

$$Ag : CaBr_2 :: 100 : 92.6503 \pm .00043$$
$$2AgBr : CaBr_2 :: 100 : 53.2232 \pm .00018$$

Hence Ag : Br : : 100 : 74.079 ± .0010.

Baxter, Thorvaldson, and Cobb made two series of analyses of ferrous bromide. From them the following ratios are derived:

Preliminary series.

$$2Ag : FeBr_2 :: 100 : 99.9573 \pm .00027$$
$$2AgBr : FeBr_2 :: 100 : 57.4221 \pm .00114$$

Hence Ag : Br : : 100 : 74.078 ± .0035.

Final series.

$$2Ag : FeBr_2 :: 100 : 99.9575 \pm .00057$$
$$2AgBr : FeBr_2 :: 100 : 57.4213 \pm .00029$$

Hence Ag : Br : : 100 : 74.078 ± .0013.

Hönigschmid's data relative to radium bromide give these ratios:

$$2Ag : RaBr_2 :: 100 : 178.812 \pm .0009$$
$$2AgBr : RaBr_2 :: 100 : 102.714 \pm .0019$$

Hence Ag : Br : : 100 : 74.087 ± .0035.

From the work of Hönigschmid on uranium tetrabromide we have these ratios:

Series 1.

$$4\ Ag : Ubr_4 :: 100 : 129.253 \pm .0015$$
$$4\ AgBr : UBr_4 :: 100 : 74.248 \pm .00025$$

Hence Ag : Br :: 100 : 74.083 ± .0074.

Series 2.

$$4\ Ag : UBr_4 :: 100 : 129.272 \pm .0006$$
$$4\ AgBr : UBr_4 :: 100 : 74.2617 \pm .00014$$

Hence Ag : Br :: 100 : 74.076 ± .0028.

In their determinations of the atomic weight of carbon, Richards and Hoover exactly neutralized sodium carbonate with aqueous hydrobromic acid. The bromine in the solution was then determined by titration with a standard solution of silver. The amount of silver used, and that of the silver bromide formed were both ascertained. First, however, the hydrobromic acid was standardized. 100 grammes of the HBr solution were equivalent to

4.77442 ± .000001 grammes of silver, and
8.31125 ± .000018 grammes of silver bromide.

Hence Ag : Br :: 100 : 74.080 ± .0004. This value might fairly have been classes among the *direct* determinations.

The other ratios derived from the work of Richards and Hoover are as follows:

$$2\ Ag : Na_2CO_3 :: 100 : 49.1265 \pm .00032$$
$$2\ AgBr : Na_2CO_3 :: 100 : 28.2206 \pm .00032$$

Hence Ag : Br :: 100 : 74.081 ± .0017.

The general combination of the indirect determinations is as follows:

Hönigschmid, U series 2	74.076 ±.0028
Richards, Sr series	74.077 ±.0016
Richards and Rogers, Zn series	74.077 ±.0024
Thorpe and Francis, Sr series	74.077 ±.0067
Cooke, Sb series	74.078 ±.0219
Richards and Hönigschmid, Ca series	74.079 ±.0010
Archibald, Pt series	74.080 ±.0070
Richards and Hoover, HBr series	74.080 ±.0004
Richards and Hoover, Na_2CO_3 series	74.081 ±.0017
Richards and Müller, K series	74.081 ±.0012
Hönigschmid, U series 1	74.083 ±.0074
Huntington, Cd series	74.086 ±.0098
Baxter, Fe series	74.087 ±.0049
Hönigschmid, Ra series	74.087 ±.0035
General mean	74.0802±.00033

The final combination of the three groups of values is as follows:

Direct determinations	74.0795±.00035
Incidental determinations	74.0803±.00035
Indirect determinations	74.0802±.00033
General mean of 39 series	74.0800±.00022

Ag : Br :: 100 : 74.0800 ± .00022.

THE SILVER-IODINE RATIO.

The composition of silver iodide, first thoroughly investigated by Marignac and Stas, has recently been the subject of elaborate researches.

Marignac [1] dissolved weighed quantities of silver in nitric acid, and precipitated the silver iodide with a solution of potassium iodide. He gives the following weights, and the ratio of AgI to 100 parts of Ag:

Ag.	*AgI.*	*Ratio.*
15.000	32.625	217.500
14.790	32.170	217.512
18.545	40.339	217.520
	Mean,	217.511±.0036

Corrected for weighing in air this becomes 217.5335.

Three series of determinations are given by Stas,[2] all with weights corrected to a vacuum.

In the first series of experiments Stas converted a known weight of silver into nitrate, and then precipitated with pure hydriodic acid. The iodide thus thrown down was washed, dried, and weighed without transfer. His figures are as follows:

Ag.	*AgI.*	*Ratio.*
97.5915	212.2905	217.529
43.5281	94.6984	217.536
	Mean,	217.5325±.0024

In the second series a complete synthesis of silver iodide from known weights of iodine and metal was effected. The iodine was dissolved in a solution of ammonium sulphite, and thus converted into ammonium iodide. The silver was transformed into sulphate and the two solutions were mixed. When the precipitate of silver iodide was completely deposited the supernatant liquid was titrated for the trifling excess of iodine which it always contained. As the two elements were weighed out in the ratio of 127 to 108, while the atomic weight of iodine is probably a little under 127, this excess is easily explained. From these experiments

[1] Oeuvres Complètes, 1, 86.

[2] Oeuvres Complètes, 1, 548–583.

two sets of values were deduced; one from the weights of silver and iodine actually employed, the other from the quantity of iodide of silver collected. From the first set we have of iodine for 100 parts of silver:

117.5390	117.5430
117.5380	117.5420
117.5318	117.5300
	Mean, 117.5373±.0015

From the weight of silver iodide actually collected the following figures are given for the ratio Ag : I. The third experiment in the foregoing column has no equivalent here:

117.529	117.538
117.531	117.530
117.539	
	Mean, 117.5334±.0014

These determinations, by Marignac and Stas, are remarkably concordant, and yet, as shown by later investigations, they are affected by constant errors. Silver iodide, precipitated from nitrate solutions, occludes silver nitrate, a fact which must be taken into account in two of the preceding series. The concordance between the second and third series of Stas, however, remains unexplained, if we suppose them to be in error also. That the errors in four sets of determinations, by two observers and four methods, should be so exactly alike in direction and magnitude, is difficult to understand.

With Ag = 107.93, the Marignac-Stas determinations of this ratio make I = 126.85. This value was accepted for many years, until Ladenburg, in 1902, showed that it was about one-tenth of a unit too low. Ladenburg [1] depended upon the ratio AgI : AgCl to establish this conclusion, but he also gave one measurement of the ratio now under consideration, as follows: 50.3147 grammes Ag gave 109.4608 AgI, whence the ratio Ag : AgI = 217.552; a figure higher than those in the foregoing tables, but not strikingly so.

Soon after the publication of Ladenburg's memoir, Scott [2] reported two syntheses of silver iodide, as follows, with weights corrected to a vacuum:

Ag.	*AgI.*	*Ratio.*
4.6240	10.0634	117.6340
6.39978	13.92913	117.6502
		Mean, 117.6421± .0054

Koethner and Aeuer,[3] who also studied what might be called the Ladenburg ratio, succeeded in proving the occlusion of silver nitrate by silver iodide, to which allusion has already been made. They effected two syntheses of silver iodide, however, avoiding this error, and by two methods. First, silver iodide was precipitated from solution with pure hydriodic acid. Secondly, silver was directly combined with iodine, by heating in a stream of iodine vapor. The two syntheses are subjoined, with the ratio stated in the form Ag : AgI, and the weights corrected to a vacuum:

Ag.	*AgI.*	*Ratio.*
34.51789	75.12752	217.6347
11.37544	24.75691	217.6480
		Mean, 217.6413± .0045

The very thorough and careful experiments by Baxter [4] fall into several series, and represent several distinct methods of procedure. First, pure silver was converted into nitrate, and precipitated by a solution of ammonium iodide in presence of an excess of ammonia. All weighings in Baxter's experiments were reduced to a vacuum and various minor corrections were

[1] Ber. Deutsch. chem. Ges., 35, 2275, 1902.
[2] Proc. Chem. Soc., 18, 112, 1902.
[3] Liebig's Annalen, 337, 123. 1904.
[4] Three memoirs. First, Proc. Amer. Acad., 40, 419. 1904. Second, ibid. 41, 73. 1905. Third, Journ. Amer. Chem. Soc., 32, 1591. 1910.

applied, concerning which the original memoirs must be consulted. Two series of determinations are given, as follows:

Preliminary series.

Ag.	*AgI.*	*Ratio.*
5.23123	11.38531	217.6411
3.57039	7.77033	217.6325
4.60798	10.02804	217.6233
4.52467	9.84822	217. 6561
4.66256	10.14591	217.6039
		Mean, 217.6314± .0059

Final series.[1]

Ag.	*AgI.*	*Ratio.*
4.77244	10.38698	217.645
4.82882	10.50981	217.648
4.04262	8.79755	217. 620
1.64711	3.58515	217.663
4.85804*	10.57318	217.643
4.83482	10.52241	217.638
4.97120	10.81800	217.613
3.53858	7.70136	217.640
3.89693	8.48187	217.655
5.33031	11.60111	217.644
5.08748	11.07259	217.644
		Mean, 217.6412± .0029
		Mean, rejecting the seventh value, 217.6440± .0024

Secondly, pure iodine was weighed, converted into hydriodic acid by means of sulphurous acid, and then transformed into ammonium iodide with pure ammonia. As nearly as possible the exact equivalent of silver was dissolved in nitric acid and added to the iodine solution. The trifling excess of silver or iodine was finally determined by titration. The following results were thus obtained:

Ag.	*I.*	*Ratio.*
5.54444	6.52288	117.6473
6.27838	7.38647	117.6493
4.57992	5.38814	117.6470
		Mean, 117.6479± .0005

In Baxter's second memoir the ratio just given was redetermined with variations in the process. Iodine was converted into hydriodic acid and precipitated by a solution of silver, taking care to avoid an excess of the latter. The final adjustment was effected by titration, as before. In five of the experiments the silver iodide so produced from a known weight of iodine was collected and weighed. In the following table both ratios are expressed in the form Ag : I :: 100 : x; A representing the direct comparisons and B the silver iodide syntheses.

I.	*Ag.*	*AgI.*	*Ratio A.*	*Ratio B.*
3.29308	2.79897	.....	117.6533	.....
3.70132	3.14584	.....	117.6576	.....
3.75641	3.19258	6.94913	117.6607	117.6555
3.24954	2.76186	6.01137	117.6576	117.6589
4.12541	3.50639	7.63204	117.6543	117.6460
3.53166	3.00165	6.53351	117.6573	117.6494
2.99835	2.54842	5.54682	117.6552	117.6529
2.00015	1.69991	.....	117.6621	.....
			Mean, 117.6573± .0007	117.6525± .0015

[1] The starred figure is erroneously given in the original. The corrected figure was kindly furnished me by Professor Baxter. The seventh experiment in the series Baxter rejects.

In the final series of experiments, based upon the silver used in the preceding set, the ratio Ag : AgI was redetermined, as follows:

Ag.	*AgI.*	*Ratio.*
3.19249	6.94877	217.6600
2.76175	6.01110	217.6555
3.00189	6.53399	217.6628
2.54833	5.54659	217.6558
		Mean, 217.6585 ± .0012

In Baxter's third memoir the ratio of iodine to silver iodide was determined by a slight modification of his former process. The iodine was converted into hydriodic acid by means of hydrazine hydroxide, and then, with due precautions, precipitated by a solution of silver nitrate. The weights (in vacuo) and the usual ratio follow:

Ag.	*I.*	*Ratio.*
7.65468	9.00628	117.6572
11.43179	13.45067	117.6602
10.08571	11.86648	117.6561
7.24498	8.52461	117.6611
5.46351	6.42840	117.6606
7.05641	8.30266	117.6613
8.45904	9.95288	117.6602
5.92491	6.97131	117.6621
7.97927	9.38852	117.6614
5.58231	6.56811	117.6594
16.03902	18.87136	117.6590
15.16249	17.84091	117.6648
12.71170	14.95666	117.6606
		Mean, 117.6603 ± .0004

The determinations of the silver-iodine ratio by Gallo,[1] although numerous, are not as concordant as the foregoing series. Silver was deposited electrolytically, and in the same circuit iodine was liberated from a solution of potassium iodide, and determined afterwards by thiosulphate titration. With vacuum weights the results obtained are as follows:

Ag.	*I.*	*Ratio.*
0.18054	0.21230	117.5917
.21360	.251309	117.6541
.23103	.27181	117.6513
.24005	.28213	117.5291
.15454	.18167	117.5553
.2597	.30515	117.5010
.16229	.19080	117.5673
.300988	.35411	117.6490
.26819	.31528	117.5584
.25877	.30425	117.5755
.24422	.28703	117.5293
.20838	.24516	117.6505
.25047	.29445	117.5599
.20266	.23826	117.5664
.18316	.21533	117.5639
.37278	.43809	117.5197
.28221	.33207	117.6677
.2582	.30356	117.5677
.33963	.39923	117.5485
.33461	.39345	117.5846
.3360	.39502	117.5655
.37025	.43526	117.5584
.30824	.36233	117.5480
.36390	.42789	117.5845
		Mean, 117.5770± .0074

[1] Atti Accad. Lincei (5), 15, 24. 1906. Gaz. Chim. Ital., 36, 116.

Two more series of electrolytic measurements of the ratio between silver and iodine remain to be mentioned. Both series were made with the iodine coulometer; but the first one, by Washburn and Bates[1] is to be regarded as preliminary. The weights in grammes and the ratio as adopted here are as follows:

Ag.	*I.*	*Ratio.*
6.15289	7.2341	117.572
6.50799	7.6497	117.547
5.94510	6.9884	117.552
5.64232	6.6342	117.579
		Mean, 117.5625±.0065.

The later determinations, by Bates and Vinal,[2] are more in accord with the values found by Baxter. The data follow with vacuum weights:

Ag.	*I.*	*Ratio.*
4.10582	4.82959	117.628
4.10469	4.82862	117.637
4.09903	4.82224	117.643
4.39711	5.17273	117.640
4.10523	4.82851	117.618
4.12310	4.84942	117.616
4.10475	4.82860	117.634
4.18424	4.92130	117.615
4.10027	4.82247	117.613
4.10516	4.82844	117.619
		Mean, 117.626±.0025

Neglecting the single determination by Ladenburg, and reducing all the series to the common form of Ag:1::100:x, the various means combine thus:

Marignac	117.5335±.0036
Stas, first	117.5325±.0024
Stas, second	117.5373±.0015
Stas, third	117.5334±.0014
Scott	117.6421±.0054
Koethner and Aeuer	117.6413±.0045
Baxter, 1904, preliminary	117.6314±.0059
Baxter, 1904, Ag:AgI	117.6412±.0029
Baxter, 1904, Ag:I	117.6479±.0005
Baxter, 1905, Ag:I	117.6573±.0007
Baxter, 1905, I:AgI	117.6525±.0015
Baxter, 1905, Ag:AgI	117.6585±.0012
Baxter, 1910, I:AgI	117.6603±.0004
Gallo	117.5770±.0074
Washburn and Bates	117.5625±.0065
Bates and Vinal	117.6260±.0025
General mean	117.6454±.00026

Of these individual values, that given by Baxter's series of 1910 is probably the best, but it is not absolute and should not be assigned exclusive weight. The atomic weight of iodine derived from the general mean is only 0.019 lower than that computed from Baxter's data.

RATIOS CONNECTING THE SILVER HALIDES.

The three ratios between the silver halides, AgCl:AgBr, AgCl:AgI, and AgBr:AgI, have all been measured with a high degree of accuracy, and by essentially the same process.

When silver bromide is heated in chlorine gas, silver chloride is formed. In 1860 Dumas[3] employed this method for estimating the atomic weight of bromine. His results are as follows. In the third column I give the weight of AgBr equivalent to 100 parts of AgCl:

[1] Journ. Amer. Chem. Soc., 34, 1367. 1912. [2] Journ. Amer. Chem. Soc., 36, 916. 1914. [3] Ann. Chem. Pharm., 113, 20.

AgBr.	*Agcl.*	*Ratio.*
2. 028	1. 547	131. 092
4. 237	3. 235	130. 974
5. 769	4. 403	131. 024
		Mean, 131. 030±. 023

The two series of determinations by Baxter [1] are much more elaborate, and far more conclusive. Before being weighed, the silver bromide was fused in a current of air saturated with bromine. The figures given below are for vacuum weights, which is true for all of Baxter's data as cited in this section.

1905 Series.

AgBr.	*AgCl.*	*Ratio.*
10. 92091	8. 33538	131. 019
13. 88062	10. 59457	131. 016
8. 21484	6. 27006	131. 017
7. 87887	6. 01352	131. 020
6. 90106	5. 26735	131. 016
9. 53704	7. 27926	131. 017
		Mean, 131. 0175±. 00045

1906 Series.

AgBr.	*AgCl.*	*Ratio.*
8. 03979	6. 13642	131. 0176
8. 57738	6. 54677	131. 0170
13. 15698	10. 04221	131. 0168
12. 71403	9. 70413	131. 0167
13. 96784	10. 66116	131. 0162
13. 08168	9. 98469	131. 0174
12. 52604	9. 56059	131. 0175
11. 11984	8. 48733	131. 0170
8. 82272	6. 73402	131. 0172
11. 93192	9. 10721	131. 0162
12. 53547	9. 56767	131. 0190
17. 15021	13. 09009	131. 0167
10. 31852	7. 87572	131. 0168
		Mean, 131. 0171±. 00013

The three series combine as follows:

Dumas	131. 030 ±. 023
Baxter, 1905	131. 0175±. 00045
Baxter, 1906	131. 0171±. 00013
General mean	131. 0172±. 00012

Dumas's figures might be rejected altogether without changing the final mean.

Silver iodide, heated in chlorine, is similarly converted into chloride. This ratio has been repeatedly investigated, first by Berzelius.[2] His figures are subjoined, with the ratio AgCl:AgI :: 100 : x in the last column:

AgI.	*AgCl.*	*Ratio.*
5. 000	3. 062	163. 292
12. 212	7. 4755	163. 360
		Mean, 163. 326±. 023

There are also two early experiments by Dumas,[3] as follows:

AgI.	*AgCl.*	*Ratio.*
3. 520	2. 149	163. 793
7. 011	4. 281	163. 770
		Mean, 163. 782±. 008

[1] Proc. Amer. Acad., 41, 82. 1905. *Ibid.*, 42, 201. 1906.
[2] Ann. Chim. Phys. (2), 40, 430. 1829.
[3] Ann. Chem. Pharm., 113, 28. 1860.

The modern work upon this ratio began with an investigation by Ladenburg [1] in 1902, which showed that the previously accepted value for the atomic weight of iodine was at least a tenth of a unit too low. Ladenburg made two series of determinations, with vacuum weights; one preliminary, the other conducted with greater care. His figures are as follows:

Preliminary Series.

AgI.	*AgCl.*	*Ratio.*
31. 2558	19. 0817	163. 800
33. 7357	20. 5930	163. 821
49. 88229	30. 4525	163. 804
47. 8830	29. 2262	163. 836
60. 1435	36. 7154	163. 810
41. 3649	25. 2448	163. 855
50. 8916	31. 0664	163. 816
41. 3233	25. 2200	163. 851
80. 8139	49. 3181	163. 863
89. 5071	54. 6367	163. 822
		Mean, 163. 8278±. 0048

Final Series.

AgI.	*AgCl.*	*Ratio.*
62. 6658	38. 2526	163. 821
63. 8402	38. 9687	163. 824
74. 7576	45. 6324	163. 826
		Mean, 163. 8237±. 00103

Ladenburg was followed, in the measurement of this ratio, by Koethner and Aeuer; [2] whose observations are of the highest significance. In a number of preliminary experiments they found that silver iodide, precipitated from solutions of silver nitrate, was liable to contain occlusions of the latter salt; a fact which accounts for the low values for iodine found by Marignac and Stas. Their final determinations of the chloride-iodide ratio are as follows, with vacuum corrections:

AgI.	*AgCl.*	*Ratio.*
24. 88066	15. 18914	163. 8056
10. 24699	6. 25564	163. 8036
12. 57020	7. 67389	163. 8048
25. 18868	15. 37678	163. 8098
9. 62006	5. 87285	163. 8057
12. 26770	7. 48901	163. 8093
22. 60660	13. 80056	163. 8093
20. 98601	12. 81160	163. 8048
22. 47667	13. 72119	163. 8099
		Mean, 163. 8080±. 00057

Two series of measurements of this ratio are due to Baxter,[3] who verified the occlusion of silver nitrate by silver iodide. This source of error he obviated by fusing the iodide in an atmosphere containing iodine. In one series, the silver iodide was first converted into bromide and afterwards into chloride; in the other series the conversion was direct. Baxter's determinations appear in the two following tables:

Bromide Series.

AgI.	*AgCl.*	*Ratio.*
13. 65457	8. 33538	163. 815
17. 35528	10. 59457	163. 813
10. 27105	6. 27006	163. 811
8. 62870	5. 26735	163. 815
11. 92405	7. 27926	163. 809
		Mean, 163. 8126±. 00079

[1] Ber. Deutsch. chem. Ges., 35, 2275. 1902.

[2] Liebig's Annalen, 337, 123 and 367. 1904. *Ibid.*, 338, 362. See also Ladenburg, *ibid.*, 338, 259. A preliminary paper by Koethner and Aeuer is in Ber., 37, 2536. 1904.

[3] Proc. Ame r Acad., 40, 431. 1904. *Ibid.*, 41, 73. 1995. Journ. Amer. Chem. Soc., 26, 1593, and 27, 879.

Direct Series.

AgI.	*AgCl.*	*Ratio.*
9. 26860	5. 65787	163. 818
6. 72061	4. 10259	163. 814
11. 31825	6. 90912	163. 816
10. 07029	6. 14754	163. 810
13. 49229	8. 23649	163. 811
		Mean, 163. 8138±. 00101

The seven series for the ratio AgCl: AgI, arranged in the order of ascending magnitude, now combine thus:

Berzelius	163. 326 ±. 023
Dumas	163. 782 ±. 008
Koethner and Aeuer	163. 8070±. 00057
Baxter, bromide series	163. 8126±. 00079
Baxter, direct	163. 8138±. 00101
Ladenburg, final	163. 8237±. 00103
Ladenburg, preliminary	163. 8278±. 0048
General mean	163. 8118±. 00038

For the ratio AgI : AgBr: : 100 : x there is one set of determinations by Baxter.[1] Silver iodide was converted into bromide by heating in bromine vapor. The data are as follows:

AgI.	*AgBr.*	*Ratio.*
13. 65457	10. 92091	79. 9799
17. 35528	13. 88062	79. 9792
9. 70100	7. 75896	79. 9812
10. 27105	8. 21484	79. 9805
9. 85688	7. 88351	79. 9798
8. 62870	6. 90106	79. 9780
11. 92405	9. 53704	79. 9816
7. 56933	6. 05389	79. 9792
		Mean, 79. 9799±. 00028

THE POTASSIUM CHLORIDE-SILVER RATIOS.

These ratios have been repeatedly measured. First, let us consider the ratio Ag : KCl : : 100 : x. Marignac[2] dissolved pure silver in nitric acid, and determined the ratio by titration with a solution of potassium chloride. The data are as follows:

Ag.	*KCl.*	*Ratio.*
4. 7238	3. 2626	69. 067
21. 725	15. 001	69. 050
21. 759	15. 028	69. 066
21. 909	15. 131	69. 063
22. 032	15. 216	69. 063
25. 122	17. 350	69. 063
		Mean, 69. 062±. 0017

Corrected for weighing in air this becomes 69.098±.0017.

The work of Stas falls into several series, widely separated in point of time. His earlier experiments[3] upon this ratio may be divided into two sets, as follows: In the first set the silver was slightly impure, but the impurity was of known quantity, and corrections could therefore be applied. In the second series pure silver was employed. The potassium chloride was from several different sources, and in every case was purified with the utmost care. From 10.8 to 32.4 grammes of silver were taken in each experiment, and the weighings were reduced to a vacuum. The method of operation was, in brief, as follows: A definite weight of potassium chloride was taken, and the exact quantity of silver necessary, according to Prout's hypothesis, to balance it

[1] Proc. Amer. Acad., 41, 73. Journ. Amer. Chem. Soc., 27, 878. 1905.
[2] Oeuvres Complètes, 1, 77.
[3] Oeuvres Complètes, 1, 363, 364.

was also weighed out. The metal, with suitable precautions, was dissolved in nitric acid, and the solution mixed with that of the chloride. After double decomposition the trifling excess of silver remaining in the liquid was determined by titration with a normal solution of potassium chloride.

First series.	*Second series*
69. 105	69. 105
69. 104	69. 099
69. 103	69. 107
69. 104	69. 103
69. 102	69. 103
	69. 105
Mean, 69. 1036±. 0003	69. 104
	69. 099
	69. 1034
	69. 104
	69. 103
	69. 102
	69. 104
	69. 104
	69. 105
	69. 103
	69. 101
	69. 105
	69. 103
	Mean, 69. 1033±. 0003

In these determinations Stas did not take into account the slight solubility of precipitated silver chloride in the menstrua employed in the experiments. Accordingly, in 1882,[1] he published a new series, in which by two methods he remeasured the ratio, guarding against the indicated error, and finding the following values:

69. 1198	69. 121
69. 11965	69. 123

Mean, 69. 1209±. 0003

Corrected for a minute trace of silica contained in the potassium chloride, this mean becomes

$$69.11903 \pm .0003$$ [2]

Still later, in order to establish the absolute constancy of the ratio in question, Stas made yet another series of determinations,[3] in which he employed potassium chloride prepared from four different sources. One lot of silver was used throughout. The values obtained were as follows:

69. 1227	69. 1228	69. 1249
69. 1236	69. 1222	69. 1238
69. 1234	69. 1211	69. 1225
69. 1244	69. 1219	69. 1211
69. 1235		

A series was also begun in which one sample of potassium chloride was to be balanced against silver from various sources, but only one result is given, namely, 69.1240. This, with the previous series, gives a mean of 69.1230±.0002.

The difference between the highest and the lowest of Stas' series corresponds to a difference of 0.021 in the atomic weight of potassium. The rejection of the earlier work might be quite justifiable, but would exert a very slight influence upon our final result.

In 1903, incidentally to their work on cæsium, Richards and Archibald [4] published two analyses of potassium chloride, in which both ratios were determined. That is, the silver

[1] Oeuvres Complètes, 762–767, 775–777.
[2] Ann. Chim. Phys. (6), 7, 513. 1886.
[3] Oeuvres Complètes, 3, 516, 539.
[4] Proc. Amer. Acad., 38, 456. 1903.

chloride was weighed, giving data for the second ratio, AgCl:KCl::100:x. The results, with vacuum weights, follow:

KCl.	*AgCl.*	*Ag.*	*Ag ratio.*	*AgCl ratio.*
2.50019	4.80600	3.61747	69.114	52.022
2.50391	4.81325	3.62283	69.115	52.021
			Mean, 69.1145	52.0215
			±.0003	±.0003

In 1904 Archibald [1] gave an additional series of determinations of these ratios, also with vacuum weights, as follows:

KCl.	*AgCl.*	*Ag.*	*Ag ratio.*	*AgCl ratio.*
2.21586	4.25916	3.20598	69.116	52.026
1.99379	3.83250	2.88479	69.114	52.023
2.89977	5.57396	4.19557	69.115	52.024
4.73606	9.10362	6.85280	69.111	52.024
			Mean, 69.114	52.024
			±.0007	±.00055

The measurements of these ratios by Richards and Staehler [2] are probably the most conclusive, for every care was taken to detect and avoid constant errors, such as the authors believe were present, despite all precautions, in the work of Stas. The occlusion of silver nitrate by silver chloride is an error of this kind. The figures for the silver ratio are as follows, with vacuum weights:

KCl.	*Ag.*	*Ratio.*
3.88074	5.61536	69.109
7.44388	10.77156	69.107
5.00681	7.24514	69.106
5.04833	7.30515	69.107
8.19225	11.85412	69.109
4.99795	7.23230	69.106
5.16262	7.47042	69.107
		Mean, 69.1073±.00032

For the silver chloride ratio Richards and Staehler give the subjoined figures:

KCl.	*AgCl.*	*Ratio.*
4.36825	8.3986	52.012
5.56737	10.7038	52.013
6.41424	12.3323	52.012
3.27215	6.2913	52.011
4.83028	9.2870	52.011
		Mean, 52.0118±.00025

Several earlier measurements of the silver chloride ratio remain to be mentioned. First, Berzelius [3] found that 100 parts of KCl were equivalent to 192.4 of AgCl, a value of which, corrected for weighing in air, becomes 192.32. Hence AgCl : KCl :: 100 : 51.997.

In 1842 Marignac [4] published two determinations as follows:

KCl.	*AgCl.*	*Ratio.*
17.034	32.761	51.995
14.427	27.749	51.991
		Mean, 51.993

[1] Trans. Roy. Soc. Canada, 1904, Section III, p. 47.

[2] Publ. Carnegie Inst., Washington, No. 69, p. 7. 1907. An advance publication in Ber. Deutsch. chem. Ges., 39, 3611, contained also the figures of some preliminary experiments, which the authors discard in their final report.

[3] Poggend. Annal., 8, 1. 1826.

[4] Oeuvres Completes, 1, 60.

Four years later, Marignac [1] published a second series of determinations. The new figures are:

KCl.	*AgCl.*	*Ratio.*
15.028	28.910	51.982
15.131	29.102	51.993
15.216	29.271	51.983
		Mean, 51.986

The mean of both series, taken as one, is 51.989; which, corrected to a vacuum, becomes 52.011±.0018.

In three determinations Maumené [2] obtained the following figures:

KCl.	*AgCl.*	*Ratio.*
10.700	20.627	51.874
10.5195	20.273	51.892
8.587	16.556	51.868
		Mean, 51.878±.0049

These figures seem to represent weights in air, but they are hardly worth correcting.

Two other analyses, with vacuum reductions, were made by Thiel [3] incidentally to his research upon indium:

KCl.	*AgCl.*	*Ratio.*
7.4314	14.2903	52.003
7.4321	14.2939	51.995
		Mean, 51.999±.0027

Assembling the data for both ratios, we now have the following combinations:

Ratio Ag: KCl:: 100:x.

Marignac	69.098 ±.0017
Stas, first	69.1036±.0003
Stas, second	69.1033±.0003
Stas, third	69.1190±.0003
Stas, fourth	69.1230±.0002
Richards and Archibald	69.1145±.0003
Archibald	69.114 ±.0007
Richards and Staehler	69.1073±.00032
General mean	69.1138±.00011

Ratio AgCl:KCl::100:x.

Berzelius	51.997 ±.0049
Marignac	52.011 ±.0018
Maumené	51.878 ±.0049
Richards and Archibald	52.0215±.0003
Thiel	51.999 ±.0027
Archibald	52.024 ±.00055
Richards and Staehler	52.0118±.00025
General mean	52.0163±.00018

In the last combination the single experiment by Berzelius is given equal weight with Maumené's series. Both general means differ from Richards and Staehler's averages by less than one part in 10,500, or 0.01 per cent.

[1] Oeuvres Complètes, 1, 78. The figures of the first set are republished in this series, but not repeated here. Marignac treats the five experiments as one series.

[2] Ann. Chim. Phys. (3), 18, 41. 1846.

[3] Zeitsch. anorg. Chem., 40, 313. 1904.

POTASSIUM BROMIDE AND IODIDE RATIOS.

The ratio between silver and potassium bromide was first accurately determined by Marignac.[1] I give, with his weighings, the quantity of KBr proportional to 100 parts of Ag:

Ag.	*KBr.*	*Ratio.*
2.131	2.351	110.324
2.559	2.823	110.316
2.447	2.700	110.339
3.025	3.336	110.283
3.946	4.353	110.314
11.569	12.763	110.321
20.120	22.191	110.293
		Mean, 110.313±.005

Corrected to a vacuum this becomes 110.343, ±.005.

Stas,[2] working in essentially the same manner as when he compared potassium chloride and silver, and with bromide from several distinct sources, found the following values for this ratio:

110.361	110.336
110.360	110.344
110.360	110.332
110.342	110.343
110.346	110.357
110.338	110.334
110.360	110.335
	Mean, 110.3463±.0020

In his paper on the atomic weight of nitrogen, Dean [3] gives three measurements of the Ag : KBr ratio, but with a bromide which was supposed to be not quite pure. His results, however, are so close to later determinations that they are worth citing:

Ag.	*KBr.*	*Ratio.*
8.52439	9.40336	110.311
7.83113	8.63900	110.316
8.92432	9.84450	110.312
		Mean, 110.313±.0010

The recent measurements of this ratio by Richards and Mueller [4] differ considerably from the concordant results of Stas and Marignac. The modern work was probably based upon purer materials, especially in the case of the silver employed. For details upon this side of the discussion the original memoirs must be consulted. The figures, with vacuum weights, given by Richards and Mueller, are as follows:

KBr.	*Ag.*	*Ratio.*
4.33730	3.93164	110.318
4.18763	3.79587	110.320
4.15849	3.76943	110.321
3.67867	3.33450	110.321
3.60484	3.26776	110.315
4.78120	4.33387	110.322
5.67997	5.14860	110.321
6.41587	5.81571	110.320
2.88134	2.61184	110.318
3.64383	2.30309	110.316
3.12757	2.83504	110.318
		Mean, 110.319±.0004

[1] Oeuvres Complètes, 1, 82. Four preliminary analyses are discarded.
[2] Oeuvres Complètes, 1, 747.
[3] Journ. Chem. Soc., 77, 177. 1900.
[4] Publ. Carnegie Inst., Washington, No. 69, p. 27. 1907.

This combines with the former determinations thus:

Marignac	110.343 ±.0050
Stas	110.3463±.0020
Dean	110.313 ±.0010
Richards and Mueller	110.3190±.0004
General mean	110.3193±.00033

Richards and Mueller also determined the second ratio, AgBr:KBr::100:x. Their figures are—

KBr.	*AgBr.*	*Ratio.*
2.19027	3.45617	63.3728
4.19705	6.62285	63.3723
2.06723	3.26206	63.3719
2.58494	4.07889	63.3736
	Mean,	63.3727±.0003

When applied to the determination of the atomic weight of potassium, the Richards and Mueller ratios yield almost absolutely identical results, which also coincide with the figures obtained by Richards and Staehler with the chloride. This agreement is strong evidence in favor of the new determinations.

The ratio between silver and potassium iodide seems to have been measured only by Marignac,[1] but without remarkable accuracy. The figures are as follows:

Ag.	*KI.*	*Ratio.*
1.616	2.483	153.651
2.503	3.846	153.665
3.427	5.268	153.720
2.141	3.290	153.667
10.821	16.642	153.794
	Mean,	153.6994±.0178

Corrected to a vacuum by Marignac, this becomes 153.800.

THE SODIUM HALIDE-SILVER RATIOS.

The ratio between silver and sodium chloride has been fixed by several investigators. Pelouze[2] dissolved a weighed quantity of silver in nitric acid, and then titrated with sodium chloride. Equivalent to 100 parts of silver he found of chloride:

54.158
54.125
54.139
Mean, 54.141±.0063

By Dumas[3] we have seven experiments, with results as follows:

NaCl.	*Ag.*	*Ratio.*
2.0535	3.788	54.211
2.169	4.0095	54.097
4.3554	8.0425	54.155
6.509	12.0140	54.178
6.413	11.8375	54.175
2.1746	4.012	54.202
5.113	9.434	54.187
	Mean,	54.172±.0096

Stas,[4] applying the method used in establishing the similar ratio for potassium chloride, and working with salt from six different sources, found of sodium chloride equivalent to 100 parts of silver:

[1] Oeuvres Complètes, 1, 86.
[2] Compt. Rend., 20, 1047. 1845.
[3] Ann. Chem. Pharm., 113, 31. 1860.
[4] Oeuvres Complètes, 1, 370.

54.2093	54.2060
54.2088	54.2076
54.2070	54.2081
54.2070	54.2083
54.2070	54.2089

Mean, 54.2078±.0002

As in the case of the corresponding ratio for potassium chloride these data needed to be checked by by others which took into account the solubility of silver chloride. Such data are given in Stas' paper of 1882,[1] and four results are as follows:

54.2065	54.2091
54.20676	54.2054

Mean, 54.20694±.00045

Corrected for a trace of silica in the sodium chloride, this mean becomes 54.2047×.00045.

The elaborate research of Richards and Wells[2] upon this ratio, gave a lower value than that found by Stas. According to Richards and Wells, the silver by Stas probably contained occluded oxygen, and his silver chloride carried down occlusions of sodium salts. The new data, with vacuum weights as usual, are as follows, the last two experiments forming a small supplementary series:

NaCl.	*Ag.*	*Ratio.*
3.96051	7.30896	54.187
2.32651	4.39355	54.186
5.36802	9.90699	54.184
4.00548	7.39210	54.186
4.69304	8.66101	54.186
3.27189	6.03842	54.185
5.08685	9.38795	54.185
3.66793	9.76952	54.183
5.48890	10.12993	54.185
3.55943	6.56909	54.185
3.38684	6.25046	54.185
4.68529	8.64634	54.188

Mean, 54.1854±.00025

The five series of determinations combine thus:

Pelouze	54.141 ±.0063
Dumas	54.172 ±.0096
Stas, earlier	54.2078±.0002
Stas, later	54.2047±.00045
Richards and Wells	54.1854±.00025
General mean	54.1995±.00015

In this combination the work of Pelouze and Dumas counts for almost nothing. Stas' determinations carry high weight, and it is not easy to understand how their supposed systematic errors could have been so uniform in magnitude. Such errors should vary from experiment to experiment, and so tend to increase the "probable error" of the mean.

In their research upon the atomic weight of boron, Ramsay and Aston[3] converted borax into sodium chloride. In the latter the chlorine was afterwards estimated gravimetrically by weighing as silver chloride on a Gooch filter. Hence the ratio, AgCl: NaCl: : 100: x, as follows:

NaCl.	*AgCl.*	*Ratio.*
3.0761	7.5259	40.874
2.7700	6.7794	40.859
2.8930	7.0804	40.859
2.7360	6.6960	40.860
1.9187	4.6931	40.863

Mean, 40.867±.0033

[1] Oeuvres Complètes, 1, 768, 778. [2] Publ. Carnegie Inst., Washington, No. 28, pp. 52, 56. 1905. [3] Chem. News, 66, 92. 1892.

The same ratio was also measured, much more exactly, by Richards and Wells. The occlusion of sodium salts by the silver chloride was especially considered and guarded against. The figures obtained are as follows:

NaCl.	*AgCl.*	*Ratio.*
3.27527	8.03143	40.781
5.56875	13.65609	41.779
4.18052	10.25176	40.779
4.54319	11.14095	40.779
1.97447	4.84196	40.778
3.97442	9.74547	40.782
6.69495	16.41725	40.780
2.88692	7.07955	40.778
5.56991	13.65833	40.780
5.85900	14.36693	40.781
		Mean, 40.7797 ± .00028

This mean, combined with that of Ramsay and Aston, gives a general mean of 40.7803 ± .00028, which falls within the limits of variation of Richards and Wells' series.

For the ratio between silver and sodium bromide we have one set of measurements by Stas.[1] The bromide was prepared by saturating Na_2CO_3 with HBr. The HBr proportional to 100 parts of silver was—

95.4420	95.4426
95.4383	95.4392
Mean, 95.4405 ± .0007	

The second bromide ratio, AgBr:NaBr, is represented by two experiments, made by Richards and Wells[2] in a research upon the transition temperature of sodium bromide. With vacuum weights the figures are—

NaBr.	*AgBr.*	*Ratio.*
5.49797	10.03253	54.8014
3.64559	6.65248	54.8005
		Mean, 54.8010 ± .0005

THE AMMONIUM HALIDE-SILVER RATIOS.

Ratios connecting silver with the chloride and bromide of ammonium have been repeatedly determined by methods essentially the same as those adopted in the similar analyses of potassium and sodium halides.

For the ammonium chloride equivalent to 100 parts of silver, Pelouze[3] found:

49.556
49.517
Mean, 49.5365 ± .013

Marignac[4] obtained the following results. The usual ratio for 100 parts of silver is given also:

Ag.	NH_4Cl.	*Ratio.*
8.063	3.992	49.510
9.402	4.656	49.521
10.339	5.120	49.521
12.497	6.191	49.540
11.337	5.617	49.546
11.307	5.595	49.483
4.326	2.143	49.538
		Mean, 49.523 ± .0055

Corrected to a vacuum this becomes 49.556 ± .0055.

[1] Oeuvres Complètes, 1, 796. Proc. Amer. Acad., 41, 443

[2] Compt. Rend., 20, 1047. 1845.

[3] Oeuvres Complètes, 1, 89.

Stas [1] made three series of determinations of this important ratio at different times and under varying conditions. All of his weights, as usual, were reduced to a vacuum standard. The third series, published in 1882, was undertaken in order to correct for the solubility of silver chloride, which was not sufficiently guarded against in the earlier work. The values found for the ratio $Ag:NH_4Cl::100:x$ are as follows:

First series.	*Second series.*	*Third series.*
49.568	49.598	49.599
49.581	49.597	49.600
49.572	49.593	49.597
49.577	49.597	49.5987
49.595	49.5974	49.597
49.588	49.602	
49.591	49.597	Mean, 49.598±.0005
49.593	49.598	
49.600	49.592	
49.599		
49.598	Mean, 49.597±.0006	
49.597		
49.591		
49.592		
Mean, 49.589±.0018		

The first four determinations in the first series are rejected by Stas as unsatisfactory.

By Scott [2] two determinations of this ratio are available, with vacuum weights, as follows:

Ag.	*NH_4Cl.*	*Ratio.*
9.64484	4.78257	49.587
11.12810	5.51744	49.581
		Mean, 49.584±.0020

Scott also made one determination of the ratio $AgCl:NH_4Cl$. 4.7850 grammes NH_4Cl balance 12.82048 of Ag. The ratio, therefore, is 100:37.3234.

The several values for the ratios $Ag:NH_4Cl::100:x$ now combine as follows:

Pelouze	49.5365±.0130
Marignac	49.556 ±.0055
Stas, first series	49.589 ±.0018
Stas, second series	49.597 ±.0006
Stas, third series	49.594 ±.0005
Scott	49.584 ±.0020
General mean	49.5965±.00038

For the ratio between ammonium chloride and silver chloride there is a series of nine determinations by Richards, Koethner and Tiede.[3] The values are found as follows:

NH_4Cl.	*$AgCl$.*	*Ratio.*
2.02087	5.41469	37.3220
2.23894	5.99903	37.3217
1.55284	4.16076	37.3211
1.36579	3.65959	37.3209
1.61939	4.33914	37.3205
1.93795	5.19219	37.3243
2.89057	7.74498	37.3219
1.31405	3.52082	37.3223
1.82091	4.87921	37.3198
		Mean, 37.3217

[1] Oeuvres Complètes, 1, 378, 478, 781.

[2] Journ. Chem. Soc., 79, 147. 1901.

[3] Journ. Amer. Chem. Soc., 31, 6. 1909. The actual analyses were made by Tiede.

Scott's single determination of this ratio, 37.3234, falls within the limits of variation of the foregoing series. Including it in the computation, the ratio becomes

$$AgCl : NH_4Cl :: 100 : 37.3218 \pm .0003$$

All weights were reduced to a vacuum basis.

Three additional determinations, by Tiede, were not published in the original memoir. I am indebted to the kindness of Professor Richards for them and include them here. The data are as follows:

NH_4Cl.	*$AgCl$.*	*Ratio.*
1.10489	2.9607	37.3185
.95997	2.5723	37.3195
.75831	2.0186	37.3184

Mean, $37.3188 \pm .00025$

Combined with the previous series of determinations, the general mean becomes 37.3205 ± 0.0002.

For the ratio $Ag : NH_4Br :: 100 : x$ there are determinations by Stas and Scott.

Stas [1] obtained the following values for x:

90.831	90.8317
90.831	90.8311
90.8297	90.8302
90.823	

Mean, $90.8297 \pm .0008$

Scott's [2] data, rejecting three preliminary experiments in which the ammonium bromide was distinctly acid, are as follows, with vacuum weights:

Ag.	*NH_4Br.*	*Ratio.*
4.92273	4.46957	90.795
4.20661	4.63303	90.796
4.23664	4.66644	90.790
4.31464	4.75175	90.801
6.19233	6.82047	90.790
8.77664	9.66708	90.789
10.47233	11.53416	90.794
4.91997	5.41834	90.802
5.00442	5.51164	90.797
5.17914	5.70390	90.800
4.84099	5.33177	90.795
5.10677	5.62515	90.784

Mean, $90.7944 \pm .0011$

Combining this with the series by Stas, the general mean is $90.8175 \pm .00065$.

THE SILVER NITRATE RATIOS.

The quantity of silver nitrate which can be formed from a known weight of metallic silver has been determined by several investigators. Penny [3] dissolved silver in nitric acid in a flask, evaporated to dryness without transfer, and weighed. One hundred parts of silver thus gave of nitrate:

157.430	157.440
157.437	157.430
157.458	157.455

Mean, $157.4417 \pm .0033$

Marignac's [4] results were as follows. In the third column they are reduced to the common standard of 100 parts of silver:

[1] Oeuvres Complètes, 1, 801.

[2] Journ. Chem. Soc., 70, 147, 1901. For a criticism by Richards, see Proc. Amer. Phil. Soc., 43, 116, 1904.

[3] Phil. Trans., 1839.

[4] Oeuvres Complètes, 1, 88. From the sum of the weights, corrected to a vacuum, Marignac computes the ratio 1 : 157.455.

Ag.	*$AgNO_3$.*	*Ratio.*
68.987	gave 108.608	157.433
57.844	91.047	157.401
66.436	104.592	157.433
70.340	110.718	157.404
200.000	314.894	157.447
		Mean, 157.4236 ± .0061

Corrected for weighing in air this becomes 157.449.

Stas,[1] employing from 77 to 405 grammes of silver in each experiment, made two different series of determinations at two different times. The silver was dissolved with all the usual precautions against loss and against impurity and the resulting nitrate was weighed, first after long drying without fusion, just below its melting point, and again fused. Between the fused and the unfused salt there was in every case a slight difference in weight, the latter giving a maximum and the former a minimum value.

In Stas's first series there are eight experiments, but the seventh he himself rejects as inexact. The values obtained for the nitrate from 100 parts of silver are given below in two columns, representing the two conditions in which the salt was weighed. The general mean given at the end I have deduced from the means of the two columns considered separately:

Unfused.	*Fused.*
157.492	157.474
157.510	157.481
157.485	157.477
157.476	157.471
157.478	157.470
157.471	157.463
157.488	157.469
Mean, 157.4857	Mean, 157.472

General mean, 157.474 ± .0014

In the later series there are but two experiments, as follows:

Unfused.	*Fused.*
157.4964	157.488
157.4940	157.480
Mean, 157.4952	Mean, 157.484

General mean, 157.486 ± .0003

The reverse ratio, namely, the amount of silver obtainable from a weighed quantity of nitrate, has been determined electrolytically by Hardin.[2] The data obtained, however, are reducible to the same form as in the preceding series and all properly combinable together. Pure silver was dissolved in pure aqueous nitric acid, and the crystalline salt thus formed was dried, fused, and used for the determinations. The silver nitrate, mixed with an excess of pure potassium cyanide solution, was electrolyzed in a platinum dish. The results obtained, reduced to vacuum weights, were as follows:

$AgNO_3$.	*Ag.*	*Ratio.*
0.31202	0.19812	157.490
.47832	.30370	157.498
.56742	.36030	157.485
.57728	.36655	157.490
.69409	.44075	157.479
.86367	.54843	157.479
.86811	.55130	157.466
.93716	.59508	157.485
1.06170	.67412	157.494
1.19849	.76104	157.477
		Mean, 157.484 ± .0020

The most thorough and recent investigation of this ratio is that by Richards and Forbes.[3] They effected the synthesis of the nitrate from the purest silver, the nitrate having been fused

[1] Oeuvres Complètes, 1, 346, 724. [2] Journ. Amer. Chem. Soc., 18, 995. 1896. [3] Publ. Carnegie Inst., Washington, No. 69, p. 47. 1907.

and tested for such impurities as dissolved air, retained water and ammonia, and nitric or nitrous acids. Only two of these were found, and in minute traces, between 0 001 and 0.002 per cent in all. The final data, with vacuum weights, are as follows:

Ag.	$AgNO_3$.	*Ratio.*
6. 14837	9. 68249	157. 481
4. 60825	7. 25706	157. 480
4. 97925	7. 84131	157. 480
9. 07101	14. 28503	157. 480
9. 13702	14. 38903	157. 481
9. 01782	14. 20123	157. 480
		Mean, 157. 480±.0001

The impurities above mentioned may lower this value to 157.478, their maximum effect. The authors accept the intermediate figure, 157.479.

Combining the several determinations, we have—

Penny	157. 4417±. 0033
Marignac	157. 449 ±. 0061
Stas, earlier	157. 474 ±. 0014
Stas, later	157. 486 ±. 0003
Hardin	157. 484 ±. 0020
Richards and Forbes	157. 479 ±. 0001
General mean	157. 479 ±. 000095

For the direct ratio between silver nitrate and silver chloride there are two series of estimations. A weighed quantity of nitrate is easily converted into chloride, and the weight of the latter ascertained. In two experiments Turner [1] found of chloride from 100 parts of nitrate:

84. 357
84. 389
Mean, 84. 373±. 011

Penny,[2] in five determinations, found the following percentages:

84. 370	84. 367
84. 388	84. 370
84. 377	Mean, 84. 3744±. 0025

The general mean from both series is 84.3743. ± 0025.

The ratio directly connecting silver nitrate with ammonium chloride has been determined only by Stas.[3] The usual method of working was followed, namely, nearly equivalent quantities of the two salts were weighed out, the solutions mixed, and the slight excess of one estimated by titration. In four experiments 100 parts of silver nitrate were found equivalent to chloride of ammonium, as follows:

31. 489	31. 487
31. 490	31. 486
Mean, 31.488±.0006	

The similar ratio between potassium chloride and silver nitrate has been determined by both Marignac and Stas.

Marignac [4] gives the following weights. I add the quantity of KCl proportional to 100 parts of $AgNO_3$:

KCl.	$AgNO_3$.	*Ratio.*
1. 849	4. 218	43. 836
2. 473	5. 640	43. 848
3. 317	7. 565	43. 847
2. 926	6. 670	43. 868
6. 191	14. 110	43. 877
4. 351	9. 918	43. 870
		Mean, 43. 858±. 0044

Corrected to a vacuum this becomes 43.874 ± .0044.

[1] Phil. Trans., 1833. 537. [2] Phil. Trans., 1839. [3] Oeuvres Complètes, 1, 382. [4] Oeuvres Complètes, 1, 88.

Stas's[1] results are given in three series, representing silver nitrate from three different sources. In the third series the nitrate was weighed in vacuo, while for the other series this correction was applied in the usual way. For the KCl equivalent to 100 parts of $AgNO_3$ Stas found:

First series.	*Second series.*	*Third series.*
43.878	43.864	43.884
43.875	43.869	43.878
43.875	43.876	43.885
43.874		
Mean, 43.8755±.0005	Mean, 43.8697±.0023	Mean, 43.8823±.0015

Combining all four series we have—

Marignac	43.874 ±.0044
Stas, first series	43.8755±.0005
Stas, second series	43.8697±.0023
Stas, third series	43.8823±.0015
General mean	43.8759±.00046

POTASSIUM AND SODIUM NITRATE RATIOS.

Ratios connecting the alkaline nitrates, chlorates, and chlorides have been determined by Penny, Stas, and Hibbs.

The general method of working upon these ratios is due to Penny.[2] Applied to the ratio between the chloride and nitrate of potassium, it is as follows: A weighed quantity of the chloride is introduced into a flask which is placed upon its side and connected with a receiver. An excess of pure nitric acid is added, and the transformation is gradually brought about by the aid of heat. Then, upon evaporating to dryness over a sand bath, the nitrate is brought into weighable form. The liquid in the receiver is also evaporated, and the trace of solid matter which had been mechanically carried over is recovered and also taken into account. In another series of experiments the nitrate was taken, and by pure hydrochloric acid converted into chloride, the process being the same. In the following columns of figures I have reduced both series to one standard, namely, so as to express the number of parts of nitrate corresponding to 100 of chloride:

First series.	*Second series.*
KCl treated with HNO_3.	*KNO_3 treated with HCl.*
135.639	135.628
135.637	135.635
135.640	135.630
135.635	135.641
135.630	135.630
135.640	135.635
135.630	135.630
Mean, 135.636±.0011	Mean, 135.633±.0011

Stas,[3] who converted potassium chloride into nitrate, gives the following figures:

KCl.	*KNO_3.*	*Ratio.*
50.7165	68.7938	135.643
80.2610	108.8665	135.638
72.1022	99.8050	135.647
50.2175	68.1200	135.649
48.9274	63.3675	135.645
69.8836	94.7900	135.640
14.2578	19.3415	135.655
		Mean, 135.6453±.0014

[1] Oeuvres Complètes, 1, 381. [2] Phil. Trans., 1839. [3] Oeuvres Complètes, 1, 683.

These figures by Stas represent weighings in the air. Reduced to a vacuum, this mean becomes 135.6423.

The determinations made by Hibbs [1] differ slightly in method from those of Penny and Stas. He converted the nitrate into the chloride by heating in a stream of gaseous hydrochloric acid. His results were as follows, vacuum weights being given:

Weight KNO_3.	*Weight KCl.*	*Ratio.*
0.11090	0.08177	135.624
.14871	.10965	135.622
.21067	.15533	135.627
.23360	.17225	135.620
.24284	.17903	135.642
	Mean,	135.627±.0026

Now, combining, we have:

Penny, 1st series	135.636 ±.0011
Penny, 2d series	135.633 ±.0011
Stas	135.6423±.0014
Hibbs	135.627 ±.0026
General mean	135.636 ± 0007

By the same general process Penny [2] determined how much potassium nitrate could be formed from 100 parts of chlorate. He found as follows:

82.505	82.498
82.497	82.500
Mean,	82.500±.0012

For 100 parts of sodium chlorate he found of nitrate:

79.875
79.882
79.890
Mean, 79.8823±.0029

For the ratio between the chloride and nitrate of sodium Penny made two sets of estimations, as in the case of potassium salts. The subjoined figures give the amount of nitrate equivalent to 100 parts of chloride:

First series.	*Second series.*
NaCl treated with HNO_3.	*$NaNO_3$ treated with HCl.*
145.415	145.419
145.408	145.391
145.420	145.412
145.424	145.415
145.410	145.412
145.418	145.412
145.420	
Mean, 145.4164±.0015	Mean, 145.410±.0026

The sodium chloride to nitrate series of Stas [3] is as follows:

NaCl.	*$NaNO_3$.*	*Ratio.*
120.0110	174.5590	145.453
32.4837	47.2550	145.468
68.1295	99.1045	145.465
47.9226	69.7075	145.459
14.5380	21.1465	145.443
	Mean,	145.4576±.0030

[1] Doctoral dissertation, University of Pennsylvania, 1896. Work done under the direction of Professor Edgar F. Smith.
[2] Phil. Trans., 1839.
[3] Oeuvres Complètes, 1, 688.

Reduced to a vacuum basis this becomes 145.4526.

Hibbs'[1] data, obtained by the method employed in the case of the potassium compounds, are as follows, vacuum weights being stated:

Weight $NaNO_3$.	*Weight NaCl.*	*Ratio.*
0.01550	0.01066	145.403
.20976	.14426	145.404
.26229	.18038	145.410
.66645	.45829	145.429
.93718	.64456	145.399
		Mean, 145.407 ± .0026

Combining, we have as follows:

Penny, 1st series	145.4164 ± .0015
Penny, 2d series	145.410 ± .0026
Stas	145.4526 ± .0030
Hibbs	145.407 ± .0026
General mean	145.418 ± .0012

One other potassium nitrate ratio has been measured by Richards and Archibald.[2] On heating the nitrate with silica, potassium silicate is formed, and the equivalent of N_2O_5 is volatilized. The vacuum weights are given in the following table together with the ratio N_2O_5: $K_2O :: 100 : x$:

KNO_3 taken.	*N_2O_5 lost.*	*Ratio.*
1.81034	0.96692	87.227
3.14564	1.68005	87.235
2.55598	1.36512	87.235
		Mean, 87.232 ± .0017

THE LITHIUM RATIOS.

The earlier determinations of the atomic weight of lithium by Arfvedson, Stromeyer, C. G. Gmelin and Kralovanzky were all erroneous, because of the presence of sodium compounds in the material employed. The results of Berzelius, Hagen, and Hermann were also incorrect, and need no further notice here. The only investigations which we need to consider are those of Mallet, Diehl, Troost, Stas, Dittmar, and Richards and Willard.

Mallet's[3] experiments were conducted upon lithium chloride, which had been purified as completely as possible. In two trials the chloride was precipitated by nitrate of silver, which was collected upon a filter and estimated in the ordinary way. The figures in the third column represent the LiCl proportional to 100 parts of AgCl:

LiCl.	*AgCl.*	
7.1885	24.3086	29.606
8.5947	29.0621	29.574

In a third experiment the LiCl was titrated with a standard solution of silver. 3.9942 grm. LiCl balanced 10.1702 grm. Ag, equivalent to 13.511 grm. AgCl. Hence 100 AgCl = 29.563 LiCl. Mean of all three experiments, 29.581 ± .0087.

Diehl,[4] whose paper begins with a good résumé of all the earlier determinations, describes experiments made with lithium carbonate. This salt, which was spectroscopically pure, was dried at 130° before weighing. It was then placed in an apparatus from which the carbon dioxide generated by the action of pure sulphuric acid upon it could be expelled, and the loss of weight determined. From this loss the following percentages of CO_2 in Li_2CO_3 were determined:

59.422	59.440
59.404	59.401

Mean, 59.417 ± .006

[1] Dissertation, University of Pennsylvania, 1896.
[2] Proc. Amer. Acad., 38, 462. 1903.
[3] Amer. Journ. Sci., November, 1856. Chem. Gazette, 15, 7.
[4] Ann. Chem. Pharm., 121, 93.

Diehl's investigation was quickly followed by a confirmation from Troost.[1] This chemist, in an earlier paper,[2] had sought to fix the atomic weight of lithium by an analysis of the sulphate, and had found a value not far from 6.5, thus confirming the results of Berzelius and of Hagen, who had employed the same method. But Diehl showed that the $BaSO_4$ precipitated from Li_2SO_4 always retained traces of Li, which were recognizable by spectral analysis, and which accounted for the error. In the later paper Troost made use of the chloride and the carbonate of lithium, both spectroscopically pure. The carbonate was strongly ignited with pure quartz powder, thus losing carbon dioxide, which loss was easily estimated. The subjoined results were obtained:

Li_2CO_3.	CO_2.	*Per cent.*
0.970	0.577	59.485
1.782	1.059	59.427
		Mean, 59.456±.020

The lithium chloride employed by Troost was heated in a stream of dry hydrochloric acid gas, of which the excess, after cooling, was expelled by a current of dry air. The salt was weighed in the same tube in which the foregoing operations had been performed, and the chlorine was then estimated as silver chloride. The usual ratio between LiCl and 100 parts of AgCl is given in the third column:

LiCl.	*AgCl.*	*Ratio*
1.309	4.420	29.615
2.750	9.300	29.570
		Mean, 29.5925±.0145

Next in order is the work of Stas,[3] which was executed with his usual care. In three titrations, in which all the weights were reduced to a vacuum, the following quantities of LiCl balanced 100 parts of pure silver:

39.356
39.357
39.361

Mean, 39.358±.001

In a second series of experiments, intended for determining the atomic weight of nitrogen, LiCl was converted into $LiNO_3$. The method was that employed for a similar purpose with the chlorides of sodium and of potassium. One hundred parts of LiCl gave of $LiNO_3$:

162.588
162.600
162.598

Mean, 162.5953±.0025

The determinations of Dittmar[4] resemble those of Diehl; but the lithium carbonate used was dehydrated by fusion in an atmosphere of carbon dioxide. The carbonate was treated with sulphuric acid, and the CO_2 was collected and weighed in an absorption apparatus, which was tared by a similar apparatus after the method of Regnault. The following percentages of CO_2 in Li_2CO_3 were found:

59.601	59.517
59.645	59.663
59.529—rejected	60.143—rejected
59.655	59.794
59.683	59.584
59.604	

Mean of all, 59.674

Rejecting the two experiments which Dittmar regards as untrustworthy, the mean of the remaining nine becomes 59.638±.0173. This combines with the work of Diehl and Troost as follows:

[1] Zeit. Anal. Chem., 1, 402.
[2] Ann. Chim. Phys., 51, 108.
[3] Oeuvres Complètes, 1, 710–716.
[4] Trans. Roy. Soc. Edinburgh, 35, II, 429. 1889.

Diehl	59.417±.0060
Troost	59.456±.0200
Dittmar	59.638±.0173
General mean	59.442±.0054

The unique merit of the determinations by Richards and Willard [1] is, not only that their work was done with scrupulous accuracy, but that their ratios give simultaneous values for the atomic weights of lithium, silver and chlorine, which are independent of all other data. Analyses of lithium perchlorate gave directly the molecular weight of lithium chloride, with reference to oxygen alone, and with that their other ratios are reducible. The data for the perchlorate are as follows, with vacuum weights:

Preliminary series.

$LiClO_4$.	*LiCl.*	*Per cent LiCl.*
10.64596	4.24171	39.8434
12.77683	5.09073	39.8435
10.12750	4.03587	39.8506
13.04021	5.19638	39.8489
		Mean, 39.8466±.00125

Final series.

$LiClO_4$.	*LiCl.*	*Per cent LiCl.*
12.79265	5.09744	39.8466
10.55416	4.20534	39.8453
11.39912	4.54205	39.8456
11.17008	4.45070	39.8448
17.84842	7.11167	39.8448
22.58273	8.99846	39.8466
		Mean, 39.8456±.00023

The two series combined give a general mean of 39.8457±.00023. Hence LiCl=42.393.

The two other ratios determined by Richards and Willard are those between lithium chloride, silver chloride and silver. With vacuum weights, their data, first for the ratio Ag: LiCl are these:

Preliminary series. [2]

LiCl.	*Ag.*	*Ratio.*
8.99620	22.89013	39.3017
5.25395	13.36777	39.3030
		Mean, 39.3023±.00048

Final series.

LiCl.	*Ag.*	*Ratio.*
5.82422	14.82035	39.2988
6.28662	15.99687	39.2991
5.82076	14.81122	39.2996
6.70863	17.07038	39.2998
6.24717	15.89620	39.2998
7.75349	19.72977	39.2984
7.99108	20.33415	39.2988
		Mean, 39.2992±.00014

Combining the figures for this ratio we have—

Stas	39.358 ±.0011
Richards and Willard 1	39.3023±.00048
Richards and Willard 2	39.2992±.00014
General mean	39.3002±.00013

[1] Journ. Amer. Chem. Soc., 32, 4. 1910.

[2] The material used in the preliminary series contained a trace of sodium.

For the silver chloride ratio Richards and Willard give the following data:

Preliminary series.

LiCl.	*AgCl.*	*Ratio.*
4.01994	13.59125	29.5774
6.32840	21.39635	29.5770
8.99620	30.41341	29.5797
4.66824	15.78111	29.5812
5.43032	18.35734	29.5812
5.10725	17.26504	29.5815
5.74000	19.40375	29.5819
5.42038	18.32417	29.5805
5.21573	17.63280	29.5797
6.56925	22.20617	29.5817
4.84268	16.37121	29.5805
		Mean, 29.5802±.00033

Final series.

LiCl.	*AgCl.*	*Ratio.*
6.28662	21.25442	29.5779
5.82076	19.67875	29.5790
6.70863	22.68030	29.5791
6.24717	21.12073	29.5784
5.50051	18.59600	29.5790
8.34521	28.21438	29.5779
6.65987	22.51564	29.5788
		Mean, 29.5786±.00014

Combining the several series for this ratio we have—

Mallet	29.581 ±.0087
Troost	29.5925±.0145
Richards and Willard 1	29.5802±.00033
Richards and Willard 2	29.5786±.00014
General mean	29.5789±.00013

The older work, with its high probable errors, vanishes.

Richards and Willard, from their three *final* series of determinations, deduce

Ag=107.871
Cl = 35.454
Li = 6.939

From the final silver and silver chloride series of Richards and Willard, the ratio Ag : Cl :: 100 : 32.8637 is derivable. This is a little lower than the value determined by Richards and Wells directly.

In a supplementary paper Richards and Cox [1] discuss the purity of lithium perchlorate, as used by Richards and Willard, and prove its availability for atomic weight determinations.

THE SILVER CARBON RATIOS.

The determination of atomic weights by the analysis of organic silver salts has been repeatedly attempted. The measurements of this class may, for present purposes, be conveniently grouped together.

In 1840 Redtenbacher and Liebig [2] sought to determine the atomic weight of carbon, that of silver being assumed as known, by analyses of the acetate, tartrate, racemate, and malate of silver. There were five determinations with each compound, the salt being ignited and the residual silver weighed. From 1 to 9 grammes of material were used in each experiment.

[1] Journ. Amer. Chem. Soc., 36, 819. 1914. [2] Ann. Chem. Pharm., 38, 113. 1841. Mem. Chem. Soc., 1, 9. Phil. Mag., (3) 19, 210.

In the acetate the following percentages of silver were found:

64.615	64.614
64.624	64.610
64.623	

Mean, 64.6172 ±.0018

After applying corrections for weighing in air, this mean becomes 64.6006.
In the tartrate the silver was as follows:

59.297	59.293
59.299	59.293
59.287	

Mean, 59.2938 ±.0014
Or, reduced to a vacuum, 59.2806.

In the racemate we have:

59.290	59.283
59.292	59.284
59.287	

Mean, 59.2872, ±.0012
Or, corrected, 59.2758.

And from the malate:

61.996	62.059
61.972	62.011
62.015	

Mean, 62.0106 ±.0096
Or, corrected, 62.0016.

These results are by no means unimpeachable. They involve two possible sources of constant error, namely, impurity of material and the volatility of the silver. These objections have both been raised by Stas, who found that the silver tartrate, prepared as Redtenbacher and Liebig prepared it, always carried traces of the nitrate, and that he, by the ignition of that salt, could not get results at all agreeing with theirs. In the case of the acetate a similar impurity would lower the percentage of silver, and thus both sources of error would reinforce each other and make the atomic weight of carbon apparently too high. With the three other salts the two sources of error act in opposite directions, although the volatility of the silver is probably of much greater influence than the impurity. Even if we had no other data relating to the atomic weight of carbon, it would be clear from these facts that the results obtained by Redtenbacher and Liebig must be decidedly in excess of the true figure.

Strecker,[1] however, discussed the data given by Redtenbacher and Liebig by the method of least squares, using the Berzelian scale, and assuming H = 12.51. Thus treated, they gave C = 75.415, and Ag = 1348.79; or, with O = 16, C = 12.066 and Ag = 107.903. These values, of course, would change somewhat upon adoption of the modern ratio between O and H.

Observations upon silver acetate, like those of Redtenbacher and Liebig, were also made by Marignac.[2] The salt was prepared by dissolving silver carbonate in acetic acid and repeatedly recrystallizing. Two experiments gave as follows:

Acetate.	*Ag.*	*Per cent.*
3.3359	2.1561	64.633
3.0527	1.9727	64.621

Mean, 64.627±.0040

Reduced to a vacuum, this becomes 64.609.

In a second series, conducted with special precautions to avoid mechanical loss by spurting, Marignac found:

Acetate.	*Ag.*	*Per cent.*
24.717	15.983	64.665
21.202	13.709	64.661
31.734	20.521	64.666

Mean, 64.664±.0010

[1] Ann. Chem. Pharm., 59, 280. 1846.

[2] Ann. Chem. Pharm., 59, 287. 1846. Oeuvres Complètes, 1, 184.

Other experiments, comparable with the preceding series, have more recently been published by Hardin,[1] who sought to redetermine the atomic weight of silver. Silver acetate and silver benzoate, carefully purified, were subjected to electrolysis in a platinum dish, and the percentage of silver so determined. For the acetate, using vacuum weights, he gives the following data, the percentage column being added by myself:

Acetate.	*Ag.*	*Per cent.*
0.32470	0.20987	64.635
.40566	.26223	64.643
.52736	.34086	64.635
.60300	.38976	64.637
.67235	.43455	64.631
.72452	.46830	64.636
.78232	.50563	64.632
.79804	.51590	64.646
.92101	.59532	64.638
1.02495	.66250	64.637
		Mean, 64.637, ±.0011

Combining this series with those of the earlier investigators we have:

Redtenbacher and Liebig	64.6006±.0018
Marignac, 1st series	64.609 ±.0040
Marignac, 2d series	64.664 ±.0010
Hardin	64.637 ±.0011
General mean	64.6434±.0007

With silver benzoate, $C_7H_5AgO_2$, Hardin's results are as follows:

Benzoate.	*Ag.*	*Per cent.*
0.40858	0.19255	47.127
.46674	.21999	47.133
.48419	.22815	47.120
.62432	.29418	47.120
.66496	.31340	47.131
.75853	.35745	47.124
.76918	.36247	47.124
.81254	.38286	47.119
.95673	.45079	47.118
1.00840	.47526	47.130
		Mean, 47.125, ±0012

A different method of dealing with organic silver salts was adopted by Maumené,[2] in 1846, for the purpose of establishing by reference to carbon the atomic weight of silver. He effected the combustion of the acetate and the oxalate of silver, and, by weighing both the residual metal and the carbon dioxide formed, he fixed the ratio between these two substances. In the case of the acetate his weighings show that for every gramme of metallic silver the weights of CO_2 were produced which are shown in the third column:

Ag.	*CO_2.*	
8.083	6.585	0.8147
11.215	9.135	.8136
14.351	11.6935	.8148
9.030	7.358	.8148
20.227	16.475	.8145
		Mean, .81448

The oxalate of silver, ignited by itself, decomposes too violently to give good results; and for this reason it was not used by Redtenbacher and Liebig. Maumené, however, found that when the salt was mixed with sand the combustion could be tranquilly effected. The oxalate

[1] Journ. Amer. Chem. Soc., 18, 990. 1896.

[2] Ann. Chim. Phys. (3), 18, 41. 1846.

employed, however, with the exception of the sample represented in the last experiment of the series, contained traces of nitrate, so that these results involve slight errors. For each gramme of silver the appended weights of CO_2 were obtained:

Ag.	CO_2.	
14.299	5.835	0.4081
17.754	7.217	.4059
11.550	4.703	.4072
10.771	4.387	.4073
8.674	3.533	.4073
11.4355	4.658	.4073
		Mean, .40718

Now, one of these salts being formed by a dibasic and the other by a monobasic acid, it is well to reduce both to a common standard. Doing this, we have for the ratio between carbon dioxide and 100 parts of silver the following combination:

From the acetate	40.724±.0076
From the oxalate	40.718±.0185
General mean	40.723±.0071

That is, $Ag : CO_2 : : 100 : 40.723 \pm .0071$.

The experiments of Dean [1] on silver cyanide, may be conveniently summarized here, although they involve nitrogen as well as carbon. Dean's object was to determine the atomic weight of nitrogen, the values for silver and carbon being supposedly known. The cyanide was dissolved in nitric acid, or, in the last experiment in sulphuric acid, and its content of silver was determined by titration with a standard solution of potassium bromide. The silver equivalent of the latter compound was previously fixed by titration against a definite solution of silver. The weights obtained, corrected to a vacuum, are subjoined, together with a column giving the percentages of silver:

AgCN.	*Ag.*	*Per cent Ag.*
6.2671	5.0490	80.564
17.60585	14.18496	80.570
17.1049	13.7801	80.561
17.9210	14.43881	80.569
12.11215	9.75875	80.570
14.6672	11.81727	80.569
		Mean, 80.567±.0010

Still another pair of ratios, involving bromine, were measured by Scott.[2] Tetraethylammonium bromide, purified with great care, was titrated with silver solutions of known strength. The results obtained, with vacuum weights, were as follows:

$(C_2H_5)_4NBr$.	*Ag.*	*Ratio.*
5.07039	2.60146	194.906
5.26380	2.70142	194.853
7.10662	3.64683	194.876
6.79951	3.48976	194.842
2.72225	1.39695	194.871
6.24530	3.20481	194.873
5.74581	2.94853	194.870
5.21663	2.67699	194.869
		Mean, 194.870±.0045

A single experiment with the corresponding tetramethyl compound was also made. 8.64585 grammes of $(CH_3)_4$ NBr are equivalent to 6.05348 of silver. Ratio, 142.824±.0123, when the probable error is assumed equal to that of one experiment in the ethyl series. From these figures Scott deduces a value for the atomic weight of carbon much higher than that given by the direct O: C ratio.

[1] Journ. Chem. Soc., 77, 117. 1900.

[2] Journ. Chem. Soc., 95, 1200. 1909.

In a criticism of Scott's work, Thorpe [1] has pointed out the possibility of errors due to the vacuum reductions; errors discussed long ago by Marignac, and recently, in more detail, by Guye and Zachariades.[2] The substances analyzed were weighed in powder, under which conditions they are liable to condense and occlude air. A probable correction, applied to Scott's weighings, reduced the atomic weight of carbon to 12.008, in harmony with other good determinations. To this criticism Scott [3] published a rejoinder, seeking to show, on the basis of experimental evidence, that the supposed errors do not, in fact, exist. According to Guye and Zachariades, the errors noted by them in the study of 26 compounds may amount to as much as, or even more than, 3 parts in 10,000.

The determinations of the atomic weight of carbon by Richards and Hoover [4] are quite unlike any of the previous investigations. Their starting point was sodium carbonate, which was first converted into sodium bromide by a standardized solution of hydrobromic acid. The ratios between the sodium bromide, silver, and silver bromide were then determined by the usual methods. The first table following gives the ratio $2AgBr:Na_2CO_3::100:x$. The hydrobromic acid was measured by weight, 100 grammes being equivalent to 8.31135 grammes of silver bromide. The ratio stated in the third column was computed by me from the data given by Richards and Hoover. The weights, of course, refer to a vacuum.

Wt. Na_2CO_3.	*Wt. HBr solution.*	*AgBr ratio.*
4.75555	202.744	28.2211
4.80081	204.673	28.2217
4.88936	208.457	28.2204
5.63157	240.119	28.2184
4.49516	191.646	28.2210
4.86256	207.307	28.2211
		Mean, 28.2206 ± .00032

The second table gives the ratio $2\,Ag:Na_2CO_3::100:x$, as determined from the amount of silver used in precipitating the sodium bromide.

Wt. Na_2CO_3.	*Wt. Ag.*	*Ratio.*
4.75555	9.68023	49.1264
4.80081	9.77222	49.1271
4.88936	9.95301	49.1244
5.63157	11.46316	49.1276
4.49516	9.15003	49.1273
4.86276	9.89811	49.1262
		Mean, 49.1265 ± .00032

From these two ratios the cross ratio Ag:Br::100:74.081 directly follows. That ratio has already been used in a previous section of this work.

Since silver tartrate and silver racemate are isomeric compounds, their figures may be consolidated into one series. We then have the following ratios in this group, to be discussed in connection with other ratios later:

$AgC_2H_3O_2Ag::100:64.843 \pm .0007$
$Ag_2C_4H_4O_6:2Ag::100:59.2778 \pm .0009$
$Ag_2C_4H_4O_5:2Ag::100:62.0016 \pm .0096$
$AgC_7H_5O_2:Ag::100:47.125 \pm .0012$
$Ag:CO_2::100:40.723 \pm .0071$
$AgCN:Ag::100:80.567 \pm .0010$
$Ag:(C_2H_5)_4NBr::100:194.870 \pm .0045$
$Ag:(CH_3)_4NBr::100:142.824 \pm .0123$
$2Ag:Na_2CO_3::100:49.1265 \pm .00032$
$2AgBr:Na_2CO_3::100:28.2206 \pm .00032$

[1] Proc. Chem. Soc., 25, 285.
[2] Compt. Rend., 149, pp. 593, 1122.
[3] Proc. Chem. Soc., 25, 286. See also Richards and Baxter, Journ. Amer. Chem. Soc., 32, 507. Renard and Guye, Journ. Chem. Phys., 14, 55.
[4] Journ. Amer. Chem. Soc., 37, 95. 1915.

THE SULPHUR RATIOS.

The atomic weight of sulphur has been determined by means of several ratios connecting it with silver, chlorine, oxygen, hydrogen, nitrogen, sodium, and carbon. Other ratios have also been measured, but they are hardly available here. The earlier results of Berzelius were wholly inaccurate, and his later experiments upon the synthesis of lead sulphate will be used in discussing the atomic weight of lead. Erdmann and Marchand determined the amount of calcium sulphate which could be formed from a known weight of pure Iceland spar; and later they made analyses of cinnabar, in order to fix the value of sulphur by reference to calcium and to mercury. Their results will be applied in this discussion toward ascertaining the atomic weights of the metals just named.

First in order let us take up the composition of silver sulphide, as directly determined by Dumas, Stas and Cooke. Dumas' [1] experiments were made with sulphur which had been thrice distilled and twice crystallized from carbon disulphide. A known weight of silver was heated in a tube in the vapor of the sulphur, the excess of the latter was distilled away in a current of carbon dioxide, and the resulting silver sulphide was weighed.

I subjoin Dumas' weighings, and also the quantity of Ag_2S proportional to 100 parts of Ag, as deduced from them:

Weight Ag.	*Weight S.*	*Ratio.*
9.9393	1.473	114.820
9.962	1.4755	114.811
30.637	4.546	114.838
30.936	4.586	114.824
30.720	4.554	114.824
		Mean, 114.8234±.0029

Dumas used from 10 to 30 grammes of silver in each experiment. Stas,[2] however, in his work employed much larger quantities. Three of Stas' determinations were made by Dumas' method, while in the other two the sulphur was replaced by pure sulphureted hydrogen. In all cases the excess of sulphur was expelled by carbon dioxide, purified with scrupulous care. Impurities in the dioxide may cause serious error. The data are as follows, with vacuum weights:

Weight Ag.	*Weight Ag_2S.*	*Ratio.*
59.4225	68.24823	114.854
104.139	119.6078	114.853
191.9094	220.4158	114.854
150.000	172.2765	114.851
249.076	286.061	114.849
		Mean, 114.8522±.0007

The experiments made by Cooke [3] with reference to this ratio were only incidental to his elaborate researches upon the atomic weight of antimony. They are interesting, however, for two reasons: They serve to illustrate the volatility of silver, and they represent, not syntheses, but reductions of the sulphide by hydrogen. Cooke gives three series of results. In the first the silver sulphide was long heated to full redness in a current of hydrogen. Highly concordant and at the same time plainly erroneous figures were obtained, the error being eventually traced to the fact that some of the reduced silver, although not heated to its melting point, was actually volatilized and lost. The second series, from reductions at low redness, are decidedly better. In the third series the sulphide was fully reduced below a visible red heat. Rejecting the first series, we have from Cooke's figures in the other two the subjoined quantities of sulphide corresponding to 100 parts of silver:

AgS.	*S.*	*Ratio.*
7.5411	0.9773	114.889
5.0364	.6524	114.882
2.5815	.3345	114.886
2.6130	.3387	114.892
2.5724	.3334	114.891
		Mean, 114.888±.0012

[1] Am. Chem. Pharm., 113, 24. 1860. [2] Oeuvres Complètes, 1, 349. [3] Proc. Amer. Acad., 13, 47-52. 1877.

1.1357	0.1465	114.810
1.2936	.1670	114.823
		Mean, 114.8165±.0044

Now, combining all four series, we have—

Dumas	114.8234±.0029
Stas	114.8522±.0007
Cooke's 2d	114.888 ±.0012
Cooke's 3d	114.8165±.0044
General mean	114.8581±.0006

The percentage of silver in silver sulphate has been determined by Struve, by Stas, and by Scheuer. Struve [1] reduced the sulphate by heating in a current of hydrogen, and obtained these results:

Ag_2SO_4.	*Ag.*	*Per cent Ag.*
5.1860	3.5910	69.244
6.0543	4.1922	69.243
8.6465	5.9858	69.228
11.6460	8.0608	69.215
9.1090	6.3045	69.212
9.0669	6.2778	69.239
		Mean, 69.230±.004

Stas,[2] working by essentially the same method, obtained the following figures, which imply vacuum weights:

Ag_2SO_4.	*Ag.*	*Per cent. Ag.*
72.137	49.919	69.200
60.251	41.692	69.197
81.023	56.071	69.204
33.115	57.523	69.209
55.716	38.5595	69.207
63.922	44.2355	69.202
		Mean, 69.203±.0012

The third sulphur ratio to be considered is one of minor importance. When silver chloride is heated in a current of sulphuretted hydrogen the sulphide is formed. This reaction was applied by Berzelius [3] to determining the atomic weight of sulphur. He gives the results of four experiments; but the fourth varies so widely from the others that I have rejected it. I have reason to believe that the variation is due, not to error in experiment, but to error in printing; nevertheless, as I am unable to discover the cause of the mistake, I must exclude the figures from our discussion.

The three available experiments, however, give the following results. The last column contains the ratio of silver sulphide to 100 parts of chloride:

AgCl.	Ag_2S.	*Ratio.*
6.6075	5.715	86.478
9.2323	7.98325	86.471
10.1775	8.80075	86.472
		Mean, 86.4737±.0015

We have also a single determination of this value by Svanberg and Struve.[4] After converting the chloride into sulphide they dissolved the latter in nitric acid. A trifling residue of chloride, which had been inclosed in sulphide, and so protected against change, was left undissolved. Hence a slight constant error probably affects this whole ratio. The experiment of Svanberg and Struve gave 86.472 per cent of silver sulphide derived from 100 of chloride.

[1] Ann. Chem. Pharm., 80, 203. 1851.
[2] Oeuvres Complètes, 1, 410.
[3] Berzelius's Lehrbuch, 5 Aufl., 3, 1187.
[4] Journ. prakt. Chem., 44, 320. 1848.

If we assign this figure equal weight with the results of Berzelius, and combine, we get a general mean of 86.4733. ±0011.

The work done by Richards [1] relative to the atomic weight of sulphur is of a different order from any of the preceding determinations. Sodium carbonate was converted into sodium sulphate, fixing the ratio $Na_2CO_3 : Na_2SO_4 : : 100 : x$. The data are as follows, with vacuum weights:

Na_2CO_3.	Na_2SO_4.	*Ratio.*
1.29930	1.74113	134.005
3.18620	4.26790	133.950
1.01750	1.36330	133.985
2.07680	2.78260	133.985
1.22427	1.63994	133.952
1.77953	2.38465	134.005
2.04412	2.73920	134.004
3.06140	4.10220	133.997
		Mean, 133.985±.0055

The exact value of this ratio was subject to slight uncertainties due to a trace of silica in the sodium carbonate, and doubt as to its complete dehydration. Accordingly a new series of determinations has recently been made by Richards and Hoover,[2] in order to secure greater precision. The new data are as follows:

Na_2CO_3.	Na_2SO_4.	*Ratio.*
5.25191	7.03829	134.014
4.50977	6.04382	134.016
5.04233	6.75737	134.016
3.67340	4.02304	134.019
4.18724	5.61151	134.015
4.55100	6.09916	134.018
		Mean, 134.0155±.00065.

The general mean of this series, combined with the earlier one, is 134.015±.00065. That is, the old series practically vanishes.[3]

Another method for fixing the atomic weight of sulphur was adopted by Richards and Jones.[4] Silver sulphate was converted into chloride by heating in a current of pure, dry hydrochloric acid gas. The data obtained, with vacuum weights, were as follows:

Ag_2SO_4.	*AgCl.*	*Per cent AgCl.*
5.21962	4.79859	91.934
5.27924	4.85330	91.932
5.08853	4.67810	91.934
5.36381	4.93118	91.934
5.16313	4.74668	91.934
5.08383	4.67374	91.933
5.13372	4.71946	91.931
5.16148	4.74490	91.929
5.19919	4.77992	91.936
5.37436	4.94088	91.934
		Mean, 91.933±.0004

The work done by Burt and Usher[5] on the relative atomic weights of nitrogen and sulphur is in its methods entirely unlike any previous investigation. Nitrogen sulphide, N_4S_4 was decomposed by sublimation over red hot quartz wool in a quartz tube, and the liberated nitrogen was collected and measured. From its volume, assuming the weight of a liter of nitrogen to be 1.2514 grammes at 0° and 760 mm. pressure, the weight of the nitrogen was computed. The

[1] Proc. Amer. Acad., 26, 268. 1891. Incidental to work on the atomic weight of copper.
[2] Journ. Amer. Chem. Soc., 37, 108. 1915.
[3] For a discussion of Richards and Hoover's sodium carbonate ratios, see Moles, Journ. Chim. Phys., 15, 51. 1917.
[4] Publ. Carnegie Inst. Washington, No. 69, p. 69. 1907. The authors give a thorough summary and criticism of the previous work on sulphur.
[5] Proc. Roy. Soc., 85 A, 82. 1911.

weights of the nitrogen sulphide were all reduced to a vacuum. The essential data follow, with the ratio S : N : : 100 : x.

N_4S_4.	N.	Ratio.
0.469455	0.142726	43.685
.442787	.134627	43.688
.456326	.138736	43.684
.470072	.142919	43.686
.466918	.141969	43.690
.491307	.149380	43.688
.484307	.147257	43.690
		Mean, 43.687±.0006.

In order to determine simultaneously the atomic weights of sulphur, silver, and chlorine Scheuer [1] dissolved weighed quantities of silver in concentrated sulphuric acid. The sulphur dioxide thus evolved was collected, condensed to liquid by means of liquid air, and weighed. The solution of silver sulphate was evaporated to dryness and weighed and then converted into chloride by fusion in a stream of dry, gaseous hydrochloric acid. The weights obtained are as follows:

Ag.	SO_2.	Ag_2SO_4.	$AgCl$.
8.63592	2.56427	12.48100	11.47436
5.99316	1.77946	8.66142	7.96296
10.21124	3.03204	14.75768	13.56757
8.96085	2.66050	12.05023	11.90590
9.70232	2.88105	14.02239	12.89159

From these weights several ratios are derivable, three of them relating directly to the atomic weight of sulphur. They are $2Ag : SO_2 : : 100 : x$; $Ag_2SO_4 : 2Ag : : 100 : x$; and $Ag_2SO_4 : 2AgCl : : 100 : x$.

$2Ag : SO_2$.	$Ag_2SO_4 : 2Ag$.	$Ag_2SO_4 : 2AgCl$.
29.693	69.193	91.935
29.691	69.194	91.936
29.693	69.193	91.935
29.690	69.193	91.932
29.694	69.192	91.936
Mean, 29.692 ±.0007.	Mean, 69.193 ±.0002.	Mean, 91.935 ±.0006.

There is also the cross ratio, Ag : Cl :: 100 : 32.8684, which has already been used in a previous section of this work.

Two of these ratios combine with others as follows:

	$Ag_2SO_4 : 2Ag$.
Struve	69.230 ±.004
Stas	69.203 ±.0012
Scheuer	69.193 ±.0002
General mean	69.1932±.0002

	$Ag_2SO_4 : 2AgCl$.
Richards and Jones	91.933±.0004
Scheuer	91.935±.0006
General mean	91.934±.0003

In recent years attempts have been made to deduce the atomic weight of sulphur from the density of sulphur dioxide, for which there are several modern determinations. Leduc,[2] in a series of measurements, found the density to range between 2.2638 and 2.2641; in mean, 2.2639. If we take these three values for the entire series the probable error of the mean becomes ±.000067. For oxygen Leduc's density figures give 1.10514, ±.0000321. Hence the crude density ratio $O_2 : SO_2$ :: 32 : 65.553, ±.0020. From these figures, with the aid of the

[1] Arch. Sci. Phys. Nat. (4), 36, 381. 1913.

[2] Compt. Rend., 117, 219. 1893.

compressibilities and critical constants of the gases, Leduc[1] determines $SO_2 = 64.056$. From the density of H_2S he finds a molecular weight of 34.071. Hence S = 32.056. By the method of limiting densities, D. Berthelot,[2] from Leduc's figures, finds S = 32.050.

Jaquerod and Pintza[3] give for the weight of a normal liter of SO_2, 2.92664 grammes. For the corresponding volume of oxygen their weight is 1.4292 grammes. Hence the crude molecular ratio 32 : 65.528. Since individual determinations are not given, the probable error of this ratio can not be calculated, and I shall assign it equal weight with Leduc's determinations. Jacquerod and Pintza also measured the density of SO_2 at pressures lower than the normal, namely, at 570 and 380 mm. Then extrapolating to zero pressure they deduce $SO_2 = 64.01$, and S = 32.01. Jaquerod and Scheuer,[4] from the same density figures, but with measurements of compressibility, found S = 32.036.

The density determinations by Baume[5] are much more elaborate. Two series were made, in globes of different capacity, and at pressures varying slightly from the normal. His crude figures for the weight of a liter of sulphur dioxide are as follows:

Series I.	*Series II.*
2. 92886	2. 92662
2. 92592	2. 92718
2. 92683	2. 92632
2. 92500	2. 92711
	2. 92623

Mean of both series as one, 2,92667 ± .00030. As corrected by Baume the normal liter of SO_2 weighs 2.92661 grammes. The accepted value for the normal liter of oxygen is 1.42905 ± .000013 grammes. Hence the ratio $O_2 : SO_2 : : 32 : 65.534 \pm .0067$.

Still another series of determinations of the density of sulphur dioxide is due to Scheuer.[7] His figures for the weight in grammes of one liter of the gas under normal conditions are—

2. 92800	2. 92785	2. 92758	2. 92772
2. 92750	2. 92759	2. 92764	2. 92761
2. 92743	2. 92758	2. 92753	2. 92744
2. 92778	2. 92786	2. 92791	2. 92788
2. 92854	2. 92757	2. 92792	2. 92764

Mean of all, 2.92771 ± .000022.

Corrected for latitude this becomes 2.92773, the weight of the normal liter. The crude ratio to oxygen, as in Baume's series, is $O_2 : SO_2 : : 32 : 65.544 \pm .0007$. This combines with the previous series, thus—

Leduc	65. 553 ± . 0020
Jaquerod and Pintza	65. 528 ± . 0020
Baume	65. 534 ± . 0017
Scheuer	65. 544 ± . 0017
General mean	65. 543 ± . 00067

Guye,[7] in his recalculation of the density ratio for SO_2, assigns to the weight of the normal liter of oxygen the value 1.4290, and to SO_2 the value 2.9266. Hence the crude ratio is 65.536, which is close to Baume's figure and also near the general mean as given above. In reducing this by means of the critical constants he assumes $a_0 = 0.02644$, and $b_0 = 0.00255$. Baume, on the other hand, finds $a_0 = 0.02837$, and $b_0 = 0.00267$. The formula for reduction, as employed in relation to the carbon and nitrogen gases, is

$$\frac{22.412L}{(1+a_0)\ (1-b_0)}$$

[1] Ann. Chim. Phys. (7), 15, 94. 1898. Leduc here puts the density of O=1.1052. See also *ante*, p. 33.
[2] Journ. Physique (3), 8, 263. 1899.
[3] Compt. Rend., 139, 129. 1904.
[4] Compt. Rend., 140, 1384. 1905.
[5] Journ. Chim. Phys., 6, 43. 1908.
[6] Anzeiger Wien Akad., 49, 36. 1912.
[7] Journ. Chim. Phys., 5, 321. 1905.

Hence, using Guye's value for L, which is sensibly identical with that of Baume, we have—

By Guye's critical data.....$SO_2=64.068$
By Baume's critical data.....$SO_2=63.955$

The difference between these figures shows the uncertainty of the method as applied to sulphur dioxide If we accept Guye's figures, as yielding results more nearly in harmony with the chemical methods of determination, the general mean for sulphur dioxide gives $SO_2=64.068$, $\pm.00067$, and $S=32.068\pm.00067$.

Another value for the atomic weight of sulphur is derivable from the density of hydrogen sulphide, as determined by Baume and Perrot.[1] Their crude values for the weight of a liter of the gas are as follows:

1. 53934	1. 53860
1. 54126	1. 53943
1. 53843	1. 53900
1. 53862	1. 53917
1. 53789	1. 53921
1. 53843	1. 53960
1. 53798	1. 53938
1. 53890	1. 53964
1. 53929	1. 54069

Mean, $1.53916\pm.00013$.

Corrected to the usual standards, the weight of the normal liter becomes 1.5392 grammes. With the critical constants determined by Olzewski, $a_0=.01438$, and $b_0=.00240$. Hence the molecular weight of H_2S is 34.0893, and $S=32.0737\pm.0030$. This, combined with the value deduced from the density of sulphur dioxide, gives a general mean of $S=32.0683\pm.00064$.

GENERAL DISCUSSION.

There are now before us, as developed in the preceding pages, 71 ratios, from which the atomic weights of 11 elements are to be computed. These elements are hydrogen, silver, chlorine, bromine, iodine, nitrogen, carbon, sulphur, lithium, sodium, and potassium. The first 12 "ratios" are really positive values, referred to $O=16$, which can be regarded as first approximations to the true quantities. These values are applicable to the reduction of the remaining ratios, by which they are themselves to be adjusted in turn.

The rigorous method of dealing with such a mass of data is well understood.[2] The several ratios should be transformed into linear equations, and each one weighted inversely as the square of its "probable error." The 71 equations should then be combined into 11 normal equations, which, when solved, would give the 11 atomic weights now under consideration. But that method of reduction is exceedingly laborious, and would possibly be premature. There is great activity at present in the measurement of fundamental ratios, and for that reason the rigorous discussion of them may well be deferred. There is, moreover, one practical disadvantage in it, namely, that the specific influence of each individual ratio is more or less obscured, except to the computer himself. The extent to which a given ratio affects the final results is not readily seen in a general combination of all the data, whereas for present purposes some such insight is likely to be helpful in guiding future work. An approximate method of reduction is therefore adopted here, which will give highly probable values for the several atomic weights, even if it does not yield the "most probable values" of the method of least squares. The uncertainties will not be large, and perhaps no larger in reality than if the strict mathematical procedure were followed rigorously.

The 71 ratios may now be tabulated, and numbered for reference, as follows:

(1) $H=1.0078\pm.00001$.
(2) $C=12.0000\pm.00026$.
(3) $N=14.0076\pm.00012$.
(4) $S=32.0683\pm.00064$.
(5) $Cl=35.4598\pm.00025$.
(6) $Br=79.9251\pm.0013$.

[1] Journ. Chim. Phys., 6, 610. 1908. Baume and Perrot reduce their data with the aid of the constant 22.410, instead of the 22.412 adopted here. Leduc's single determination of the density (Ann. Chim. Phys. (7), 15, 35) may be neglected. His gas was not certainly pure.

[2] See Clarke, Amer. Chem. Journ., 27, 321, 1902.

(7) I=126.915±.0056.
(8) LiCl=42.393±.00029.
(9) NaCl=58.500±.0048.
(10) KCl=74.5631±.0004.
(11) KBr=119.249±.0596.
(12) KI=165.590±.0384.
(13) AgCl=143.390±.0060.
(14) AgBr=187.884±.0133.
(15) AgI=234.734±.0126.
(16) I_2O_5 : 2Ag :: 100 : 64.6229±.0001.
(17) Ag : Cl :: 100 : 32.8656±.00022.
(18) Ag : Br :: 100 : 74.0800±.00022.
(19) Ag : I :: 100 : 117.6424±.00026.
(20) AgCl : AgBr :: 100 : 131.0172±.00012.
(21) AgCl : AgI :: 100 : 163.8118±.00038.
(22) AgI : AgBr :: 100 : 79.9799±.00028.
(23) Ag : LiCl :: 100 : 39.3002±.00013.
(24) AgCl : LiCl :: 100 : 29.5789−.00013.
(25) Ag : NaCl :: 100 : 54.1995−.00015.
(26) AgCl : NaCl :: 100 : 40.7803±.00028.
(27) Ag : NaBr :: 100 : 95.4405±.0007.
(28) AgBr : NaBr :: 100 : 54.8010±.0005.
(29) Ag : KCl :: 100 : 69.1138±.00011.
(30) AgCl : KCl :: 100 : 52.0163±.00018.
(31) Ag : KBr :: 100 : 110.3193±.00033.
(32) AgBr : KBr :: 100 : 63.3727±.0003.
(33) Ag : KI :: 100 : 153.800±.0178.
(34) Ag : NO_3 :: 100 : 57.479±.000095.
(35) $AgNO_3$: AgCl :: 100 : 84.3743±.0025.
(36) $AgNO_3$: KCl :: 100 : 43.8759±.00046.
(37) $AgNO_3$: NH_4Cl :: 100 : 31.488±.0006.
(38) Ag : NH_4Cl :: 100 : 49.5965±.00038.
(39) AgCl : NH_4Cl :: 100 : 37.3205±.0002.
(40) Ag : NH_4Br :: 100 : 90.8175±.00065.
(41) NH_3 : HCl :: 100 : 214.136±.0092.
(42) Cl : N :: 100 : 39.489±.0033.
(43) Cl : NO :: 100 : 84.626±.0013.
(44) N+Cl=49.457±.0026.
(45) Br : Cl :: 100 : 44.3674±.0006.
(46) NaCl : Cl :: 100 : 60.6581±.00035.
(47) NaBr : Br :: 100 : 77.6543±.00029.
(48) NaCl : $NaNO_3$ :: 100 : 145.418±.0012.
(49) $NaClO_3$: $NaNO_3$ :: 100 : 79.8823±.0029.
(50) KCl : KNO_3 :: 100 : 135.636±.0007.
(51) $KClO_3$: KNO_3 :: 100 : 82.500±.0012.
(52) N_2O_5 : K_2O :: 100 : 87.232±.0017.
(53) LiCl : $LiNO_3$ :: 100 : 162.5953±.0025.
(54) Li_2CO_3 : CO_2 :: 100 : 59.442±.0054.
(55) 2Ag : Na_2CO_3 :: 100 : 49.1265±.00032.
(56) 2AgBr : Na_2CO_3 :: 100 : 28.2206±.00032.
(57) Ag : CO_2 :: 100 : 40.723±.0071.
(58) $AgC_2H_3O_2$: Ag :: 100 : 64.6434±.0007.
(59) $Ag_2C_4H_4O_6$: 2Ag :: 100 : 59.2778±.0009.
(60) $Ag_2C_4H_4O_5$: 2Ag :: 100 : 62.0016±.0096.
(61) $AgC_7H_5O_2$: Ag :: 100 : 47.125±.0012.
(62) AgCN : Ag :: 100 : 80.567±.0010.
(63) Ag : $C_8H_{20}NBr$ :: 100 : 194.870±.0045.
(64) Ag : $C_4H_{12}NBr$ :: 100 : 142.824±.0123.
(65) 2Ag : S :: 100 : 14.8581±.0006.
(66) 2Ag : SO_2 :: 100 : 29.692±.0007.
(67) Ag_2SO_4 : 2Ag :: 100 : 69.1932±.0002.
(68) Ag_2SO_4 : 2AgCl :: 100 : 91.934±.0003.
(69) 2AgCl : Ag_2S :: 100 : 86.4733±.0011.
(70) Na_2CO_3 : Na_2SO_4 :: 100 : 134.015±.00065.
(71) S : N :: 100 : 43.687±.0006.

In the discussion of these 71 ratios it is evidently desirable to utilize each one as completely as possible. That is, each ratio should contribute to the determination of every element whose atomic weight is involved in it. Of these atomic weights that of silver is especially important, for it appears in 43 of the ratios, and is, moreover employed in determining the atomic weights of many other elements. In order to do this, however, it is necessary to find preliminary values for lithium, sodium, and potassium, and these can be computed from several ratios in which silver does not appear. For sodium, for example, we have—

From ratios—	
5 and 9	Na=23.0402±0.0048
5 and 46	22.9987± .0003
6 and 47	22.9990± .0005
3, 5, and 48	22.9924±. 0017
3, 5, and 49	23.1736± .0050
2, 4, and 70	23.0182± .0014
General mean	Na=22.9984± .00025

For potassium there are the following values:

From ratios—	
5 and 10	K=30.1033±0.0009
5 and 50	39.0344± .0018
5 and 51	39.1240± .0085
3 and 52	39.1105± .0010
General mean	K=39.0927± .00075

Values for potassium can also be derived from ratios 10 and 11, but their probable errors are so large that they would not appreciably influence the general mean.

For lithium three values are available as follows:

From ratios—	
5 and 8	Li=6.9332±0.00037
3, 5, and 53	6.9680± .0017
2 and 54	7.0108± .0022
General mean	Li=6.9342± .00035

It must be borne in mind that these values for lithium, sodium, and potassium are *preliminary*, and that they will be modified in the final combination. For convenience of reference they may be numbered consecutively with the other ratios, thus:

(72) Na=22.9984±0.00025
(73) K=39.0927± .00075.
(74) Li= 6.9342± .00035.

With these added ratios 43 values for the atomic weight of silver can be computed, as follows:

From ratios—	
1, 2, and 60	Ag=107.717±0.0367
1, 2, and 59	107.742± .0026
6, 7, and 22	107.801± .0235
7 and 15	107.809± .0138
1, 3, 6, and 63	107.809± .0028
1, 3, and 64	107.824± .0058
6, 72, and 27	107.841± .0056
1, 3, 6, and 64	107.843± .0094
5, 7, and 21	107.861± .0024
8 and 24	107.862± .0014
7 and 16	107.865± .0036
5, 73, and 30	107.865± .0016
1, 3, 5, and 38	107.868± .0010
1, 3, 6, and 40	107.869± .0016
8 and 23	107.870± .00082
7, 73, and 33	107.871± .0131
2, 6, 72, and 56	107.875± .0026
1, 2, and 61	107.876± .0040
5, 73, and 29	107.878± .0014
3 and 34	107.879± .00021
6, 73, and 32	107.881± .0028
2, 72, and 65	107.881± .00086
7 and 19	107.882± .0050
5, 72, and 25	107.882± .00074
4, 5, and 68	107.884± .0059
6, 73, and 31	107.885± .0014
4 and 67	107.886± .00081
6, 72, and 28	107.888± .0034
4 and 66	107.888± .0028
5, 72, and 26	107.889± .00066
1, 3, 5, and 39	107.889± .0012
6 and 18	107.890± .0018
3, 5, and 35	107.891± .0272
5 and 17	107.893± .00077
1, 3, 5, and 37	107.895± .0035
5, 6, and 20	107.897± .0044
3, 5, 73, and 36	107.899± .0026
1, 2, and 58	107.914± .0025
4 and 65	107.915± .0049
5 and 13	107.930± .0060
6 and 14	107.959± .0133
2 and 57	108.047± .0193
4, 5, and 69	108.137± .0118
General mean[1]	Ag=107.8804± .00016

[1] Guye (Journ. Chem. Phys., 17, 171, 1919), from a discussion of selected data relative to the atomic weight of silver, concludes that the best value for this constant is Ag=107.87.

This final mean is almost identical with the value derived from ratio 29, which gives the composition of silver nitrate. That ratio, moreover, is presumably the best of all, and has the smallest probable error. It dominates the entire combination; but its rejection would only raise the atomic weight of silver to 107.883. If we should reject all the values for silver dependent upon analyses of chlorates, bromates, and iodates, which are generally high, the final mean becomes 107.877. It is clear, therefore, that the true value can not be very far from the general mean of all, namely,

$$Ag = 107.880 \pm .00016.$$

As for the widely aberrant values, especially the first two and the last four, their probable errors are so large that it is a matter of no moment whether they are retained or rejected. Their influence is negligible.

With the aid of the value thus found for silver, we can now compute 32 values for the atomic weight of chlorine, as follows:

From ratios—	
3, 72, and 49	Cl=35.4152±.0039
3, 73, and 50	35.4453±.0010
2, 35, and Ag	35.4470±.0011
3 and 44	35.4494±.0027
1, 3, and 41	35.4517±.0054
7, 21, and Ag	35.4520±.0035
3, 73, and 51	35.4532±.0022
4, 68, and Ag	35.4535±.0012
1, 3, 37, and Ag	35.4537±.0010
1, 3, 39, and Ag	35.4558±.00051
17 and Ag	35.4564±.00058
3, 72, and 48	35.4579±.00058
74 and 8	35.4588±.00051
3 and 43	35.4591±.00056
73 and 46	35.4594±.00075
5	35.4598±.00025
6 and 45	35.4607±.00075
3, 35, and Ag	35.4615±.0042
72, 26, and Ag	35.4619±.00088
5, 74, and 23	35.4628±.0004
6, 20, and Ag	35.4630±.0011
5, 74, and 24	35.4651±.00058
1, 3, 38, and Ag	35.4659±.00044
73, 29, and Ag	35.4672±.00076
4, 69, and Ag	35.4676±.0020
3, 74, and 53	35.4677±.00077
10 and 74	35.4704±.00085
72, 25, and Ag	35.4722±.00029
3 and 42	35.4722±.0030
73, 30, and Ag	35.4756±.0017
9 and 72	35.5016±.0049
13 and Ag	35.5096±.0061
General mean	Cl=35.4605±.00011

This general mean for chlorine is nearly identical with the atomic weight derived from the syntheses and density of hydrochloric acid. It will be used in future reductions in place of ratio 5. The extremely low and high values tend to balance one another, but even if they did not, they are vastly outweighed by the determinations with much smaller probable errors.

For bromine the ratios give the following 16 values:

From ratios—	
7, 22, and Ag	Br=79.9090±.0041
73, 31, and Ag	79.9127±.00085
72, 28, and Ag	79.9153±.0022
18 and Ag	79.9175±.00026

From ratios—	
2, 72, 56, and Ag	Br=79.9204±.0027
20, Cl, and Ag	79.9205±.00035
72 and 47	79.9225±.0014
73, 31, and Ag	79.9234±.0026
45 and Cl	79.9247±.00024
6	79.9251±.0013
1, 3, 40, and Ag	79.9351±.00085
7, 27, and Ag	79.9626±.00081
1, 2, 3, 64, and Ag	79.9771±.0166
14 and Ag	80.0040±.0134
73 and 11	80.1563±.0596
1, 2, 3, 63, and Ag	80.1621±.0166
General mean	Br=79.9228±.00015

The general mean agrees well with the best determined values for the atomic weight of bromine. The last four values, with their higher probable errors, are without significance.

Iodine appears in only eight of the ratios, from which the following values are derived:

From ratios—	
73 and 12	I=126.497±.0385
73, 33, and Ag	126.826±.0192
15 and Ag	126.854±.0127
19 and Ag	126.913±.00034
7	126.915±.0056
21, Cl, and Ag	126.929±.00067
22, Br, and Ag	126.932±.00098
16 and Ag	126.938±.00036
General mean	I=26.926±.00023

The three low values, with their large probable errors, have only slight influence upon this combination. At most they effect only the fourth decimal place.

Nitrogen appears in 22 of the ratios from which the following values are derived:

From ratios—	
73 and 52	N=13.9928±.0012
44 and Cl	13.9965±.0027
74, 53, and Cl	13.9976±.0013
1, 37, Cl, and Ag	14.0002±.0015
42 and Cl	14.0030±.0012
1, 39, Cl, and Ag	14. 0037±00032
1, 41, and Cl	14.0070±.00074
3	14.0076±.00012
35, Cl, and Ag	14.0078±.0078
34 and Ag	14.0083±.00014
43 and Cl	14.0088±.00047
4 and 71	14.0097±.00034
72, 48, and Cl	14.0114±.00085
1, 38, Cl, and Ag	14.0130±.00043
73, 51, and Cl	14.0137±.0018
1, 40, Br, and Ag	14.0199±.00074
2, 62, and Ag	14.0210±.0014
1, 2, 64, and Ag	14.0266±.0148
73, 50, and Cl	14.0283±.0014
73, 36, Cl, and Ag	14.0383±.0025
72, 48, and Cl	14.0434±.0032
1, 2, 63, and Ag	14.1469±.0212
General mean	N=14.0081±.00008

In this combination the value found for the atomic weight of nitrogen lies between that directly determined and represented by ratio 3, and that derived from the composition of silver nitrate as given by ratio 34. All the other values might be rejected and the final result would be the same as that given in the foregoing table.

The atomic weight of potassium is deducible from 12 ratios, as follows:

From ratios—	
12 and I	K=38.6440±.0384
50, N, and Cl	39.0361±.0015
36, N, Cl, and Ag	39.0794±.00090
31, Br, and Ag	39.0896±.00042
32, Br, and Ag	39.0929±.00026
33, I, and Ag	39.0931±.0181
29, Cl, and Ag	39.0995±.00020
30, Cl, and Ag	39.0999±.00020
10 and Cl	39.1026±.00042
52 and N	39.1123±.00092
51, N, and Cl	39.1246±.0085
11 and Br	39.3262±.0596
General mean	K=39.0975±.00011

Here again, the extreme values, with their high probable errors, count for nothing. The final value is determined by the ratios which represent analyses of potassium chloride and bromide. The preliminary value for K (ratio 73) was much lower.

The atomic weight of sodium is derivable from 12 ratios, as follows:

From ratios—	
48, N, and Cl	Na=22.9913±.0016
26, Cl, and Ag	22.9942±.00042
28, Br, and Ag	22.9952±.00096
2, 55, and Ag	22.9976±.00038
47 and Br	22.9985±.00032
46 and Cl	22.9989±.00025
2, 56, Br, and Ag	22.9990±.00062
25, Cl, and Ag	23.0099±.00022
2, 4, and 70	23.0182±.0014
27, Br, and Ag	23.0384±.00078
9 and Cl	23.0395±.0049
49, N, and Cl	23.1741±.0050
General mean	Na=23.0029±.00012

This value is perhaps a little too high, on account of the low probable error derived from ratio 25, the ratio between silver and sodium chloride. The four highest values have very slight influence upon the general mean. The last value in the series is without significance.

Lithium appears in only five of the ratios, which give the following values:

From ratios—	
8 and Cl	Li=6.9325±.00031
23, Cl, and Ag	6.9366±.00019
24, Cl, and Ag	6.9380±.00022
53, N, and Cl	6.9670±.0017
2 and 54	7.0108±.0022
General mean	Li=6.9368±.00013

For sulphur the following values are found:

From ratios—	
65 and Ag	S=32.0578±.0013
2, 70, and Na	32.0579±.00088
67 and Ag	32.0625±.0011
66 and Ag	32.0635±.0015
71 and N	32.0647±.00045
4	32.0683±.00064
68, Cl, and Ag	32.0735±.0015
69 Cl, and Ag	32.1453±.0033
General mean	S=32.0650±.00012

The final value is identical with that adopted by Richards and Hoover.

The atomic weight of carbon is given by 13 ratios, but with widely varying results. The values are as follows:

From ratios—	
54 and Li	C=11.7829±.0071
57 and Ag	11.9320±.0070
55, Na, and Ag	11.9895±.00074
1, 58, and Ag	11.9905±.0014
56, Na, Br, and Ag	11.9922±.0012
2	12.0000±.00026
1, 61, and Ag	12.0009±.00058
1, 64, N, Br, and Ag	12.0046±.0027
70, S, and Na	12.0053±.0006
62, N, and Ag	12.0128±.0014
1, 63, N, Br, and Ag	12.0181±.0006
1, 60, and Ag	12.0269±.0098
1, 59, and Ag	12.0474±.0012
General mean	C=12.0025±.00019

That this mean is higher than the atomic weight given in ratio 2, does not prove it to be in error. That derived from ratio 70, as determined by Richards and Hoover, is still higher and entitled to much credit. The general mean of all determinations agrees well with the results obtained by modern physical methods, and may, therefore, stand, until it is superseded by something of less uncertainty.

As for hydrogen, new values for its atomic weight can be deduced from 11 of the fundamental ratios. The computation has been roughly made, and found to be without significance. The combined values, so obtained, are of such small weight in comparison with ratio (1) that they only modify it in the sixth decimal place, a change which is not worth considering.

To sum up: The subjoined values, referred to O=16 as the standard, have been computed from all the ratios, old and new, good, bad, and indifferent:

H= 1.0078±.00001	Br= 79.9228±.00015
C=12.0025±.00019	I=126. 926±.00023
N=14.0081±.00008	Li= 6.9368±.00013
S=32.0650±.00012	Na= 23.0029±.00012
Cl=35.4605±.00011	K= 39.0975±.00011
Ag=107.880±.00016	

That these values are final, is not to be supposed. That they are, in the strict mathematical sense, the most probable values deducible from the experimental data, is also questionable. But that they are highly probable values, in harmony with the best modern evidence, can safely be asserted. The inferior determinations, low in weight, have practically vanished, one might almost say self-rejected, but not thrown out arbitrarily. The good measurements overwhelm the doubtful ones, whose influence upon the final computations is almost negligible. The 11 values as given above, will be used in calculating the atomic weights of all the other elements.

RUBIDIUM.

The atomic weight of rubidium has been determined by analyses of the chloride and bromide.

Bunsen,[1] employing ordinary gravimetric methods, estimated the ratio between AgCl and RbCl. His rubidium chloride was purified by fractional crystallization of the chloroplatinate. He obtained the following results, to which, in a third column, I add the ratio between RbCl and 100 parts of AgCl:

RbCl.	*AgCl.*	*Ratio.*
1.000	1.1873	84.225
1.000	1.1873	84.225
1.000	1.1850	84.388
1.000	1.1880	84.175
		Mean, 84.253±.031

Hence Rb=85.309.

[1] Zeit. Anal. Chem., 1, 136. Poggend. Annal., 113, 339. 1861.

The work of Piccard [1] was similar to that of Bunsen. In weighing, the crucible containing the silver chloride was balanced by a precisely similar crucible, in order to avoid the correction for displacement of air. The filter was burned separately from the AgCl, as usual; but the small amount of material adhering to the ash was reckoned as metallic silver. The rubidium chloride was purified by Bunsen's method. The results, expressed according to the foregoing standard, are as follows:

RbCl.	*AgCl.*	*Ag.*	*Ratio.*
1.1587	1.372	+.0019	84.300
1.4055	1.6632	+.0030	84.303
1.001	1.1850	+.0024	84.245
1.5141	1.7934	+.0018	84.313
			Mean, 84.290±.0105

Hence Rb = 85.361.

Godeffroy,[2] starting with material containing both rubidium and cæsium, separated the two metals by fractional crystallization of their alums, and obtained salts of each spectroscopically pure. The nitric acid employed was tested for chlorine and found to be free from that impurity, and the weights used were especially verified. In two of his analyses of RbCl the AgCl was handled by the ordinary process of filtration. In the other two it was washed by decantation, dried and weighed in a glass dish. The usual ratio is appended in the third column:

RbCl.	*AgCl.*	*Ratio.*
1.4055	1.6665	84.338
1.8096	2.1461	84.320
2.2473	2.665	84.326
2.273	2.6946	84.354
		Mean, 84.3345±.0051

Hence Rb = 85.425.

Heycock [3] worked by two methods, but unfortunately his results are given only in abstract, without details. First, silver solution was added in slight deficiency to a solution of rubidium chloride, and the excess of the latter was measured by titration. The mean of seven experiments gave—

Ag : RbCl :: 107.93 : 120.801

Hence Rb = 85.285.

Two similar experiments with the bromide gave—

Ag : RbBr :: 107.93 : 165.437
Ag : RbBr :: 107.93 : 165.342

Mean, 165.3895 ± .0320

Hence Rb = 85.390.

The determinations by Archibald [4] were made with scrupulously purified materials, and with all of the precautions observed in the best modern investigations. The chloride and bromide were precipitated with known weights of silver, and the silver halide produced was also weighed. Two ratios were thus measured for each salt, and checked by the cross ratios between silver and chlorine or bromine, respectively. The weights, corrected to a vacuum, are given below, and also the four principal ratios:

Weight RbCl.	*Weight AgCl.*	*Weight Ag.*	*AgCl ratio.*	*Ag ratio.*
1.99966	2.37070	1.78454	84.349	112.054
2.06480	2.44778	1.84241	84.354	112.070
2.29368	2. 71960	2.04710	84.339	112.046
1.09495	1.29796	.97702	84.360	112.070
2.14381	2.54118	1.91316	84.364	112.056
2.89700	3.43475	2.58550	84.344	112.047
2.19692	2.60452	1.96076	84.350	112.044
2.14543	2.54386	1.91462	84.338	112.055

[1] Journ. prakt. Chem., 86, 454. 1862. Zeit. Anal. Chem., 1, 518.
[2] Ann Chem. Pharm., 181, 185. 1876.
[3] British Association Report, 1882, 449.
[4] Journ. Chem. Soc., 85, 776. 1904.

Weight RbCl.	*Weight AgCl.*	*Weight Ag.*	*AgCl ratio.*	*Ag ratio.*
2.12164	2.51557	1.89346	84.341	112.052
2.25777	2.67685	2.01515	84.344	112.040
2.18057	2.58528	1.94594	84.346	112.057
2.32699	2.75878	2.07668	84.348	112.053
4.00035	2.74233	3.56998	84.354	112.055
2.43440	2.88613	2.17233	84.348	112.064
			Mean, 84.3485, ±.0014	112.0545, ±.0016

From the AgCl ratio, Rb = 85.445.
From the Ag ratio, Rb = 85.424.
And Ag : Cl :: 100 : 32.847.
The values for the AgCl ratio combine as follows:

Bunsen	84.253 ±.031
Piccard	84.290 ±.0105
Godeffroy	84.3345±.0051
Archibald	84.3485±.0013
General mean	84.3433±.0013

Heycock's single value for the Ag ratio, reduced to the usual standard, becomes Ag : RbCl :: 100 : 111.926. It is not worth while to combine it with Archibald's values, for its influence would be quite negligible. In the AgCl ratio the older determinations count for something, but the general mean falls within the range of variation of Archibald's series.

The bromide analyses by Archibald are as follows:

Weight RbBr.	*Weight AgBr.*	*Weight Ag.*	*AgBr ratio.*	*Ag ratio.*
2.68170	3.04578	1.74930	88.047	153.301
2.07280	2.35401	1.35230	88.054	153.280
2.10086	2.38589	1.37061	88.053	153.278
2.61044	2.96462	1.70300	88.053	153.285
3.84082	4.36215	2.50590	88.049	153.272
3.77852	4.29084	2.46502	88.061	153.287
4.34299	4.93210	2.83340	88.56	153.278
			Mean, 88.0533 ±.0012	153.283, ±.0024

From the Ag ratio, Rb = 85.439.
From the AgBr ratio, Rb = 85.444.
And Ag : Br :: 100 : 74.080.

Heycock's mean for the Ag ratio, reduced, becomes Ag : RbBr :: 100 : 153.238 ±0300. Its probable error is so high that combination with Archibald's data would be useless.

There are now four ratios from which to compute the atomic weight of rubidium:

(1) Ag: RbCl :: 100 : 112.0545 ±.0016
(2) AgCl : RbCl :: 100 : 84.3433 ±.0013
(3) Ag : RbBr :: 100 : 153.283 ±.0024
(4) AgBr :: 100 : 88.0533 ±.0012

Reducing these ratios with Ag = 107.880 ±.00016, Cl = 35.4605 ±.00011, and Br = 79.9228 ±.00015, we have—

From ratio—	
1	Rb=85.424±.0017
2	85.438±.0019
3	85.439±.0026
4	85.444±.0023
General mean	Rb=85.434±.0010

CÆSIUM.

The atomic weight of cæsium, like that of rubidium, has been computed from analyses of the chloride and bromide, and also from experiments upon the nitrate. The earliest determination, by Bunsen,[1] was incorrect, because of impurity in the material studied. The first trustworthy determinations were published by Johnson and Allen [2] in 1863. Their material was extracted from the lepidolite of Hebron, Maine, and the cæsium was separated from the rubidium as bitartrate. From the pure cæsium bitartrate cæsium chloride was prepared, and in this the chlorine was estimated as silver chloride by the usual gravimetric method. Reducing their results to the convenient standard adopted in preceding chapters, we have, in a third column, the quantities of CsCl equivalent to 100 parts of AgCl:

CsCl.	*AgCl.*	*Ratio.*
1.8371	1.5634	117.507
2.1295	1.8111	117.580
2.7018	2.2992	117.511
1.56165	1.3302	117.399
		Mean, 117.499±.025

Hence Cs = 132.963.

Shortly after the results of Johnson and Allen appeared a new series of estimations was published by Bunsen.[3] His cæsium chloride was purified by repeated crystallizations of the chloroplatinate, and the ordinary gravimetric process was employed. The following results represent, respectively, material thrice, four times and five times purified:

CsCl.	*AgCl.*	*Ratio.*
1.3835	1.1781	117.435
1.3682	1.1644	117.503
1.2478	1.0623	117.462
		Mean, 117.467±.013

Hence Cs = 132.917.

Godeffroy's work [4] was, in its details of manipulation, sufficiently described under rubidium. In three of the experiments upon cæsium the silver chloride was washed by decantation, and in one it was collected upon a filter. The results follow.

CsCl.	*AgCl.*	*Ratio.*
1.5825	1.351	117,135
1.3487	1.1501	117.265
1.1880	1.0141	117.148
1.2309	1.051	117.107
		Mean, 117.164±.023

Hence Cs = 132.483.

The foregoing investigations may now be regarded as merely preliminary, in comparison with the more elaborate determinations made by Richards and Archibald.[5] Their material was purified by fractional crystallization as cæsium dichloriodide, from which the chloride, bromide, and nitrate were afterwards prepared. The chloride and bromide were freed from possible traces of moisture by fusion in an atmosphere of nitrogen, and analyzed by the usual method. That is, they were precipitated by known weights of silver dissolved as nitrate, and the silver chloride or bromide produced was also weighed. All the weights given are reduced to a vacuum standard. The results obtained with cæsium chloride are given in the next table:

Weight CsCl.	*Weight AgCl.*	*Weight Ag.*	*AgCl ratio.*	*Ag ratio.*
3.83054	3.26240	2.45600	117.415	155.967
3.95120	3.36532	2.53351	117.409	155.958
2.27237	1.93555	1.45686	117.402	155.977
3.02935	2.58003	1.94244	117.415	155.956
3.19774	2.72382	2.05023	117.399	155.970

[1] Zeitsch. Anal. Chem., 1, 137.
[2] Amer. Journ. Sci. (2), 35, 94.
[3] Poggend. Annalen, 119, 1. 1863.
[4] Ann. Chem. Pharm., 181, 185. 1876.
[5] Proc. Amer. Acad., 38, 443. 1903.

Weight CsCl.	*Weight AgCl.*	*Weight Ag.*	*AgCl ratio.*	*Ag ratio.*
2.35068	2.00253	1.50270	117.386	155.963
2.06245	1.75678	1.32251	117.399	155.950
2.56372	2.18358	.....	117.409	.....
2.01881	1.71972	1.29434	117.392	155.972
1.77391	1.51093	1.13743	117.405	155.958
3.08160	2.62484	1.97590	117.401	155.959
3.13117	2.66720	2.00760	117.395	155.966
5.06656	4.31570	3.24850	117.398	155.966
			Mean, 117.402	155.9635
			±.0016	±.0016

From Ag ratio, Cs = 132.793.
From AgCl ratio, Cs = 132.820.
And Ag:Cl::100:32.846.

There is also a single analysis of cæsium chloride made by Stewart [1] for Richards, whose figures are as follows:

CsCl.	*Ag.*	*AgCl.*	*Ag ratio.*	*AgCl ratio.*
0.72285	0.46336	0.61583	156.002	117.378

To each of these ratios the probable error of one determination by Richards and Archibald, ±.0069, may be assigned. Combining the silver ratio with the value found by Richards and Archibald, the weighted mean is Ag:CsCl::100:155.966 ±.0016. The silver chloride ratio combines with the others as follows:

Johnson and Allen	117.499±.025
Bunsen	117.467±.013
Godeffroy	117.164±.023
Richards and Archibald	117.402±.0016
Stewart	117.378
General mean	117.403±.0016

The older determinations practically vanish, leaving the Richards and Archibald mean almost unchanged.

The figures for the bromide series are as follows

Weight CsBr.	*Weight AgBr.*	*Weight Ag.*	*AgBr ratio.*	*Ag ratio.*
3.49820	3.08815	1.77402	113.278	197.192
6.20409	5.47673	3.14606	113.281	197.202
2.17300	6.33213	2.63740	113.279	197.201
			Mean, 113.279	197.198
			±.0007	±.0045

From Ag ratio, Cs = 132.814.
From AgBr ratio, Cs = 132.818.
And Ag:Br::100:74.078.

When cæsium nitrate is fused with finely powdered silica, cæsium silicate is formed, and the elements of the nitric radicle are expelled. With weighed quantities of the nitrate, the loss of weight is equivalent to N_2O_5. The ratio $N_2O_5:Cs_2O::100:x$ is thus easily determined. In four experiments Richards and Archibald obtained the following results:

Weight $CsNO_3$.	*Weight N_2O_5.*	*Ratio.*
3.76112	1.04273	260.699
3.33334	.92416	260.689
4.81867	1.33590	260.706
5.04807	1.39960	260.679
		Mean, 260.693±.0039

Hence Cs = 132.795.

[1] Journ. Amer. Chem. Soc., 37, 289. 1915.

The five ratios for the atomic weight of cæsium are now as follows:

(1) Ag : CsCl :: 100 : 155.96 ± .0016
(2) AgCl : CsCl :: 100 : 117.403 ± .0016
(3) Ag : CsBr :: 100 : 197.198 ± .0045
(4) AgBr : CsBr :: 100 : 113.279 ± .0007
(5) N_2O_5 : Cs_2O :: 100 : 260.693 ± .0039

Reducing these ratios with—

Ag= 107.880±.00016	Br=79.9228±.00015
Cl= 35.4605±.00011	N=14.0081±.00008

we have—

From ratio—	
5	Cs=132.795±.0021
1	132.796±.0017
3	132.814±.0049
4	132.819±.0013
2	132.826±.0023
General mean	Cs=132.811±.00084

COPPER.

The atomic weight of copper has been chiefly determined by means of the oxide, the sulphate and the bromide, and by direct comparison of the metal with silver.

In dealing with the first-named compound nearly all experimenters have agreed in reducing it with a current of hydrogen, and weighing the metal thus set free.

The earliest experiments of any value were those of Berzelius,[1] whose results were as follows:

CuO.	*O.*	*Per cent Cu in CuO.*
7.68075	1.55	79.820
9.6115	1.939	79.826
		Mean, 79.823±.002

Hence Cu = 63.298.

Erdmann and Marchand,[2] who come next in chronological order, corrected their results for weighing in air. Their weighings, thus corrected, give us the subjoined percentages of metal in CuO:

CuO	*Cu.*	*Per cent.*
63.8962	51.0391	79.878
65.1590	52.0363	79.860
60.2878	48.1540	79.874
46.2700	36.9449	79.846
		Mean, 79.8645±.0038.

Hence Cu = 63.462.

Still later we find a few analyses by Millon and Commaille.[3] These chemists not only reduced the oxide by hydrogen, but they also weighed, in addition to the metallic copper, the water formed in the experiments. In three determinations the results were as follows:

CuO.	*Cu.*	H_2O.	*Per cent.*
6.7145	5.3565	1.5325	79.775
3.3945	2.7085	.7680	79.791
2.7880	2.2240	....	79.770
			Mean, 79.7787±.0043

Hence Cu = 63.125.

For the third of these analyses the water estimation was not made, but for the other two it yielded results which, in sum, would make the atomic weight of copper 63.165. This figure has so high a probable error that we need not consider it further.

[1] Poggend. Annual., 8, 177. 1826. [2] Journ. prakt. Chem., 31, 380. 1844. [3] Fresenius' Zeitschrift, 2, 475. 1863.

The results obtained by Dumas [1] are wholly unavailable. Indeed, he did not even publish them in detail. He merely says that he reduced copper oxide, and also effected the synthesis of the subsulphide, but without getting figures which were wholly concordant. He puts Cu = 63.5.

In 1873 Hampe [2] published his careful determinations, which were for many years almost unqualifiedly accepted. First, he attempted to estimate the atomic weight of copper by the quantity of silver which the pure metal could precipitate from its solutions. This attempt failed to give satisfactory results, and he fell back upon the old method of reducing the oxide. From 10 to 20 grammes of material were taken in each experiment, and the weights were reduced to a vacuum.

CuO.	*Cu.*	*Per cent.*
20.3260	16.2279	79.838
20.68851	16.51669	79.835
10.10793	8.06926	79.831
		Mean, 79.8347 ± .0013

Hence Cu = 63.344.

Hampe also determined the quantity of copper in the anhydrous sulphate, $CuSO_4$. From 40 to 45 grammes of the salt were taken at a time, the metal was thrown down by electrolysis, an dthe weights were all corrected. I subjoin the results:

$CuSO_4$.	*Cu.*	*Per cent.*
40.40300	16.04958	39.724
44.64280	17.73466	39.726
		Mean, 39.725 ± .0007

The last series of data gives Cu = 63.314, and is interesting for comparison with results obtained by Richards later.

In all of the foregoing experiments with copper oxide, that compound was obtained by ignition of the basic nitrate. But, as was shown in the chapter upon oxygen, copper oxide so prepared always carries occluded gases, which are not wholly expelled by heat. This point was thoroughly worked up by Richards [3] in his fourth memoir upon the atomic weight of copper, and it vitiates all the determinations previously made by this method.

By a series of experiments with copper oxide ignited at varying temperatures, and with different degrees of heat during the process of reduction, Richards obtained values for Cu ranging from 63.20 to 63.62. In two cases selected from this series he measured the amount of gaseous impurity, and corrected the results previously obtained. The results were as follows, with a vacuum reduction :

CuO	*Cu.*	*Per cent.*
1.06253	.84831	79.802
1.91656	1.5298	79.820
		Mean, 79.811 ± .0061

Correcting for the occluded gases in the oxide, the sum of the two experiments gives 79.901 per cent of copper, whence Cu = 63.605. The other indirect results, similarly corrected, gave 79.900 per cent Cu in CuO, or Cu = 63.603. If we assign all five experiments equal weight, and judge their value by the two detailed above, the mean percentage becomes 79.900 ± .0038.

The experiments on copper oxide, by Murmann,[4] are of very doubtful utility. Copper was oxidized by heating in oxygen, and the oxide was also reduced in hydrogen, giving values for Cu varying from 63.513 to 64.397. The five experiments, with all corrections, including reduction to a vacuum, and rejecting the excessively high figure given above, may be stated in the following form :

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[1] Ann. Chim. Phys. (3), 55, 129. 1859.
[2] Fresenius' Zeitschrift, 13, 352.
[3] Proc. Amer. Acad., 26, 276. 1891.
[4] Monatsh. Chemie., 27, 351. 1906.

Cu.	*CuO.*	*Per cent Cu.*
1.13625	1.41856	80.099
2.64333	3.30923	79.878
1.07874	1.35045	79.880
5.12489	6.41350	79.908
3.33515	4.17315	79.919
		Mean, 79.937±.0278

Hence Cu=63.749. Murmann himself selected values from his series varying between 63.512 and 63.560.

The determinations by Oechsner de Coninck and Ducelliez [1] are of very slight value. Copper was oxidized by nitric acid, but without consideration of gaseous inclusions in the oxide so formed, and with no reduction of the weights to a vacuum. The data are as follows:

Cu.	*CuO.*	*Per cent Cu.*
0.2200	0.2754	79.884
.2860	.3580	79.888
.3740	.4682	79.881
.2421	.3030	79.901
.2664	.3335	79.880
		Mean, 79.887±.0026

Hence Cu=63.551.

The several series for the percentage of copper in copper oxide now combine as follows, although for practical purposes the combination has small significance.

Berzelius	79.823 ±.0020
Erdmann and Marchand	79.8645±.0038
Millon and Commaille	79.7787±.0043
Hampe	79.8347±.0013
Richards	79.900 ±.0038
Murmann	79.937 ±.0278
Oechsner and Ducelliez	79.887 ±.0026
General mean	79.842 ±.0009

This result is not far from that of Hampe, whose work receives excessive weight, as does also that of Berzelius. The oxide of copper is evidently of doubtful value in the measurement of this atomic weight.

The composition of copper sulphate has been studied, not only by Hampe, but also by Baubigny [2] and by Richards. [3] Baubigny merely ignited the anhydrous salt, weighing both it and the residual oxide, as follows:

$CuSO_4$.	*CuO.*	*Per cent.*
4.022	2.0035	49.813
2.596	1.293	49.807
		Mean, 49.810±.002

Hence, Cu=63.459.

The same ratio, in reverse—that is, the synthesis of the sulphate from the oxide—was investigated by Richards, who shows that the results obtained are vitiated by the same errors which affect the copper oxide experiments previously cited. The weights given are reduced to a vacuum. The percentage of oxide in the sulphate is stated in the third column of figures:

CuO.	$CuSO_4$.	*Per cent.*
1.0084	2.0235	49.835
2.7292	5.4770	49.830
1.0144	2.0350	49.848
		Mean, 49.838±.0036

Hence, Cu=63.548.

[1] Rev. Gén. Chim., 16, 122. 1913. [2] Compt. Rend., 97, 906. 1883. [3] Proc. Amer. Acad., 26, 240. 1891.

The two series combine thus:

Baubigny	49.810±.0020
Richards	49.838±.0036
General mean	49.816±.0017

Here, plainly, the rigorous discussion gives Baubigny's work weight in excess of its merits.

In the memoir by Richards, now under consideration, his fourth upon copper, the greater part of his attention is devoted to the sulphate, Hampe being followed closely in order to ascertain what sources of error affected the work of the latter. Crystallized sulphate, $CuSO_4.5H_2O$, was purified with every precaution and made the basis of operations. Three series of experiments were carried out, the water being determined by loss of weight upon heating, and the copper being estimated electrolytically. In the first series the following data were found, the weights being reduced to a vacuum, as in all of Richards' determinations:

	$CuSO_4$. 5 aq.	*$CuSO_4$ at 250°.*	*Cu.*
1	2.8815	.....	0.7337
2	2.7152	.....	.6911
3	3.4639	2.2184	.8817

Hence the subjoined percentages:

	Water at 250°.	*Cu. in Cryst. Salt.*	*Cu in $CuSO_4$.*
1	.....	25.462	.....
2	.....	25.452	.....
3	35.958	25.454	39.745
		Mean, 25.456	

In the second series of analyses, which are stated with much detail, several refinements were introduced in order to estimate also the sulphuric acid. These will be considered later. The results given below are numbered consecutively with the former series:

	$CuSO_4$.5 aq.	*$CuSO_4$ at 260°.*	*$CuSO_4$ at 360°.*	*Cu.*
4	3.06006	1.9597	1.95637	0.77886
5	2.81840	1.8048	.....	.71740
6	7.50490	4.8064	4.79826	1.90973

Hence percentages as follows:

	Water, 260°.	*Water, 360°.*	*Cu in Cryst. Salt.*	*Cu in $CuSO_4$, 260°.*	*Ditto, 360°.*
4	35.959	36.068	25.452	39.744	39.811
5	35.964	.....	25.454	39.750	.....
6	35.957	36.065	25.446	39.733	39.799
Mean,	35.960	36.067	25.450	39.742	39.805

Hampe worked with a sulphate dried at 250°, but these data show that a little water is retained at that temperature, and consequently that his results must have been too low. The third of Richards' series resembles the second, but extra precautions were taken to avoid conceivable errors.

	$CuSO_4$.5 aq.	*$CuSO_4$ at 260°.*	*$CuSO_4$ at 370°.*	*Cu.*
7	2.88307	.....	.....	0.73380
8	3.62913	2.32373	.....	.92344
9	5.81352	.....	3.71680	1.47926

And the percentages are:

	Water at 260°.	*At 370°.*	*Cu in Cryst. Salt.*	*Cu in $CuSO_4$.*
7	.....	.....	25.452	.....
8	35.970	.....	25.446	39.740(260°)
9	.....	36.067	25.445	39.799(370°)
			25.448	

In this series the determinations of sulphuric acid gave essentially the same results for all three samples of sulphate, although one was not dehydrated, and the others were heated to

60° and 370°, respectively. Hence the loss of weight in dehydration at either temperature represents water only, and does not involve partial decomposition of the sulphate. Between 360° and 400° copper sulphate is at essentially constant weight, but further experiments indicated that even at 400° it retained traces of water, and possibly as much as .042 per cent. The last trace is not expelled until the salt itself begins to decompose.

Richards also effected two syntheses of the sulphate directly from the metal by dissolving the latter in nitric acid, then evaporating to dryness with sulphuric acid, and heating to constant weight at 400°.

Cu.	*$CuSO_4$.*	*Per cent Cu.*
0.67720	1.7021	39.786
1.00613	2.5292	39.781

If we include these percentages in a series with the data from analyses 4, 6, and 9, which gave percentages of 39.811, 39.799 and 39.799, respectively, of copper in sulphate dried at 360° and upwards, the mean becomes

$$CuSO_4 : Cu :: 100 : 39.795 \pm .0036$$

Hence, Cu = 63.498.

Since even this result is presumably too low, the other figure from sulphate dried at 250° must be rejected. Since Hampe's work on the sulphate is affected by the same sources of error, and apparently to a still greater extent, it need not be considered farther. As for Richards' nine determinations of Cu in $CuSO_4.5H_2O$, we may take them as one series giving a mean percentage of $25.451 \pm .0011$, and Cu = 63.55. This salt seems to retain occluded water, for the percentage of copper in it leads to a value for the atomic weight which is inconsistent with the best evidence, as will be seen later.

In the second and third series of Richards' experiments upon copper sulphate, the sulphuric acid was estimated by a method which gave valuable results. After the copper had been electrolytically precipitated, the acid which was set free was nearly neutralized by a weighed amount of pure sodium carbonate, and the slight excess remaining was determined by titration. Thus the weight of sodium carbonate equivalent to the copper was ascertained. The resulting solution of sodium sulphate was then evaporated to dryness, and a new ratio, connecting that salt with copper, was also determined. The cross ratio $Na_2CO_3 : Na_2SO_4$ has already been utilized in a previous chapter. The results, ignoring the weights of hydrated copper sulphate, are as follows, with the experiments numbered as before:

	Cu.	*Na_2CO_3.*	*Na_2SO_4.*
4	.77886	1.2993	1.7411
6	1.90973	3.1862	4.2679
7	.73380	1.22427	1.63994
8	.92344	1.54075	.....
9	1.47926	.....	3.30658

Hence,

$Cu : Na_2CO_3 :: 100 : x$.	*$Cu : Na_2SO_4 :: 100 : x$.*
166.824	223.549
166.840	223.482
166.840	223.538
166.849	223.529
Mean, 166.838 ± .0035	Mean, 223.525 ± .0098
Hence Cu = 63.540.	Hence Cu = 63.559.

In their work upon the atomic weight of sulphur, which is cited in a former section of this recalculation, Richards and Hoover have shown that the sodium carbonate of the foregoing series of determinations must have retained traces of water. This calls for a correction of +0.022 in the atomic weight of copper as derived from the sodium carbonate ratio; and raises it from 63.540 to 63.562. In the summing up at the end of this section this correction will be applied.

In one more experiment the sulphuric acid was weighed as barium sulphate, the latte being corrected for occluded salts. 3.1902 grm. $CuSO_4.5H_2O$ gave 2.9761 $BaSO_4$; hence $CuSO_4.5H_2O : BaSO_4 :: 100 : 93.289$. The sulphate contained 25.448 per cent of Cu; hence $BaSO_4$: Cu :: 93.289 : 25.448, and Cu = 63.676. As this ratio rests upon a single determination needs no further consideration here.

In his third paper upon the atomic weight of copper,[1] Richards studied the dibromide, $CuBr_2$. In preparing this salt he used hydrobromic acid made from pure materials, and further purified by 10 distillations. This was saturated with copper oxide prepared from pure electrolytic copper, and the solution obtained was proved to be free from basic salts. As the crystallized compound was not easily obtained in a satisfactory condition, weighed quantities of the solution were taken for analysis, in which, after expulsion of bromine by nitric and sulphuric acids, the copper was determined by electrolysis. In other portions of solution the bromine was precipitated by silver nitrate, and weighed as silver bromide. The first preliminary series of experiments gave the subjoined results, with vacuum weights as usual:

In 25 grammes of solution.

Cu.	*AgBr.*
0.4164	2.4599
.4164	2.4605
.4164	2.4605
.4165	2.4599

Hence 2AgBr : Cu :: 100 : 16.927 ± .0013.

The second, also preliminary series, was made with more dilute solutions, and came out as follows:

In 25 grammes of solution.

Cu.	*AgBr.*
0.26190	1.5478
.26185	1.5477
	1.5479

Hence 2AgBr : Cu :: 100 : 16.919 ± .0012.

In the third series, two distinct lots of crystallized bromide were dissolved, and the solutions examined in the same way:

Cu.	*AgBr.*	*Ratio.*
0.2500	1.4771	16.925
.5473	3.2348	16.919
		Mean, 16.922 ± .0020

In the final set of analyses, the materials used were purified even more scrupulously than before, and the process was distinctly modified, as regards the determination of the bromine. The solution of the bromide was added to a solution of pure silver in nitric acid, not quite sufficient for complete precipitation. The slight excess of bromine was then determined by titration with a solution containing 1 gramme of silver to the liter. Thus silver proportional to the copper in the bromide was determined, and the silver bromide was weighed in a Gooch crucible as before. The results are subjoined:

In 50 grammes of solution.

Cu.	*Ag.*	*AgBr.*
0.54755	1.8586	3.2350
.54750	1.8579	3.2340
	1.8583	3.2348

Hence Cu : 2Ag :: 100 : 339.392 ± .0108, and 2AgBr : Cu :: 100 : 16.927 ± .0012.

The latter ratio, combined with the results of the three preceding series, gives a general mean of

2AgBr : Cu : : 100 : 16.924 ± .0007

Hence Cu = 63.567.

[1] Proc. Amer. Acad., 25, 195. 1880.

In his two earlier papers [1] Richards determined the copper-silver ratio directly—that is, without the weighing of any compound of either metal. By placing pure copper in an *ice-cold* solution of silver nitrate, metallic silver is thrown down, and the weights of the two metals are in equivalent proportions. In the first paper the following results are given. The third column gives the value of x in the ratio Cu: 2Ag: : 100: x.

Cu taken.	*Ag found.*	*Ratio.*
0.53875	1.8292	339.527
.56190	1.9076	339.491
1.00220	3.4016	339.414
1.30135	4.4173	339.440
.99870	3.39035	339.477
1.02050	3.4646	339.500
		Mean, 339.475 ± .0114

In the second paper Richards states that the silver of the fifth experiment, which had been dried at 150°, as were also the others, still retained water, to the extent of four-tenths milligramme in 2 grammes. If we assume this correction to be fairly uniform, as the concordance of the series indicates, and apply it throughout, the mean value for the ratio then becomes 339.408 ± .0114. This procedure, however, leaves the ratio in some uncertainty, and accordingly some new determinations were made, in which the silver, collected in a Gooch crucible, was heated to incipient redness before final weighing. Copper from two distinct sources was taken, and three experiments were carried out upon one sample to two with the other. Treating both sets as one series, the results were as follows:

Cu taken.	*Ag found.*	*Ratio.*
0.75760	2.5713	339.40
.95040	3.2256	339.39
.75993	2.5794	339.42
1.02060	3.4640	339.42
.90460	3.0701	339.39
		Mean, 339.404 ± .0046

a value practically identical with the corrected mean of the previous determinations, and with that found in the later experiments upon copper bromide. Hence Cu = 63.570.

In various electrical investigations the same ratio, the electrochemical equivalent of copper, has been repeatedly measured, and the later results of Lord Rayleigh and Mrs. Sidgewick,[2] Gray,[3] Shaw,[4] and Vanni [5] may properly be included in this discussion. As the data are somewhat differently stated, I have reduced them all to the common standard adopted above. Gray gives two sets of measurements, one made with large and the other with small metallic plates:

Rayleigh and S.	*Gray 1.*	*Gray 2.*	*Shaw.*	*Vanni.*
340.483	341.297	340.252	339.68	340.483
340.832	341.413	339.674	340.05	340.600
340.367	340.815	340.020	339.84	340.367
	340.252	339.905	339.71	340.252
340.561,	339.905	339.674	340.04	340.600
± .0935	341.064	339.328	339.94	340.136
	340.832	340.136	340.35	
	341.297	340.136	339.82	340.406
	341.064	340.136	340.09	± .0520
	341.413	340.020	339.84	
		340.020	339.90	
	340.935	340.136	339.98	
	± .1072		340.14	
		339.953	340.56	
		± .0521	339.82	
			339.983	
			± .0411	

[1] Proc. Amer. Acad., 22, 346, and 23, 177. 1886 and 1887.
[2] Phil. Trans., 175, 458.
[3] Phil. Mag. (5), 22, 389.
[4] British Assoc. Report, 1886. Abstract in Phil. Mag. (5), 23, 138.
[5] Ann. der Phys. (Wiedemann's) (2), 44, 214.

The lack of sharp concordance in these data and the consequently high probable errors seem to indicate a distinct superiority of the purely chemical method of determination over that adopted by the physicist. This supposition is strengthened by the electrochemical experiments of Richards, Collins, and Heimrod,[1] who precipitated copper and silver simultaneously in the same current of electricity. Their first series, with vacuum weights, is as follows:

Weight Cu.	*Weight Ag.*	*Ratio.*
0.44478	1.51064	339.64
.31645	1.07473	339.63
.24968	.84792	339.60
1.02186	3.47056	339.63
.66166	2.24538	339.36
.63027	2.14050	339.63
.45919	1.55905	339.72
.39177	1.33071	339.67
1.11030	3.76990	339.54
.67564	2.29655	339.91
.48232	1.63768	339.54
.83092	2.82203	339.63
.63491	2.15735	339.79
.70102	2.37868	339.32
.84469	2.86608	339.55
.87462	2.97114	339.71
.69405	2.35683	339.58
		Mean, 339.615±.0230

Hence Cu = 63.531.

In a second series of experiments the copper was deposited from solutions saturated with cuprous sulphate:

Weight Cu.	*Weight Ag.*	*Ratio.*
0.71847	2.43935	339.52
.71861	2.43940	339.46
.72019	2.44603	339.64
.97193	3.30100	339.63
.50916	1.72859	339.50
.76188	2.58664	339.51
		Mean, 339.543±.0200

Hence Cu = 63.544.

In the foregoing series the temperature of the solution was 0°. Two experiments at higher temperatures, 56°–61°, gave lower values for the ratio, and consequently a higher atomic weight for copper:

Weight Cu.	*Weight Ag.*	*Ratio.*
0.97295	3.30100	339.28
.76214	2.58664	339.39
		Mean, 339.335±.0370

Hence Cu = 63.583.

More recent is an electrochemical series of determinations by Gallo,[2] of slight importance. The figures, with vacuum weights, are—

Weight Cu.	*Weight Ag.*	*Ratio.*
0.21805	0.73937	339.083
.27153	.92062	339.049
.19001	.64571	339.829
.39585	1.34578	339.972
		Mean, 339.483±.164

Hence Cu = 63.555.

The electrolytic comparison of copper and silver by simultaneous precipitation in voltameter cells by Shrimpton[3] is of exceptional value because of the care taken to determine and

[1] Proc. Amer. Acad., 35, 123. 1899. [2] Atti. Acad. Lincei (5), 14, 23. 1905. [3] Proc. Physical Soc., 26, 292. 1914.

apply all recognized corrections. The corrected weights are as follows, with the corresponding ratio:

Weight Cu.	*Weight Ag.*	*Ratio.*
0.65307	2.21666	339.422
1.27349	4.32294	339.456
.64410	2.18635	339.443
.63262	2.14751	339.463
.95574	3.24431	339.455
.67704	2.29784	339.397
1.04351	3.54245	339.474
1.15428	3.91820	339.450
1.42326	4.83168	339.480
.71831	2.43829	339.448
		Mean, 339.449±.0052

Hence Cu = 63.562.

Still another electrolytic comparison of the same two metals by Pecheux[1] gave Cu = 63.43. As no details as to weights or the number of experiments are given, this determination need not receive any further attention.

The general combination of all data relative to the copper-silver ratio is as follows:

Richards, first series, corrected	339.408±.0114
Richards, second series	339.404±.0046
Richards, $CuBr_2$ series	339.392±.0108
Richards, Collins, and Heimrod, first	339.615±.0230
Richards, Collins, and Heimrod, second	339.543±.0200
Richards, Collins, and Heimrod, third	339.335±.0370
Rayleigh and Sidgewick	340.561±.0935
Gray, large plates	340.935±.1072
Gray, small plates	339.953±.0521
Shaw	339.983±.0411
Vanni	340.406±.0520
Gallo	339.483±.1640
Shrimpton	339.449±.0052
General mean	339.431±.0037

We now have the following ratios from which to compute the atomic weight of copper.

(1) Percentage of Cu in CuO, 79.842±.0009
(2) Percentage of Cu in $CuSO_4$, 39.795±.0036
(3) Percentage of Cu in $CuSO_4$, $5H_2O$, 25.451±.0011
(4) Percentage of CuO in $CuSO_4$, 49.816±.0017
(5) Cu : Na_2CO_3 :: 100 : 166.838±.0035
(6) Cu : Na_2SO_4 :: 100 : 223.525±.0098
(7) 2AgBr : Cu :: 100 : 16.924±.0007
(8) Cu : 2Ag :: 100 : 339.431 ±.0031.

To reduce these ratios we have—

Ag=107.880±.00016	C=12.0025±.00019
Cl=35.4605±.00011	S=32.0650±.00012
Br=79.9228±.00015	Na=23.0029±.00012
H=1.0078±.00001	

Hence

From ratio—

1	Cu=63.3730±.0025
4	63.4779±.0038
2	63.4982±.0069
3	63.5525±.0029
6	63.5592±.0028
5, corrected	63.5631±.0013
8	63.5652±.00059
7	63.5675±.0026
General mean	Cu=63.5550±.00050

[1] Compt. Rend., 154, 1919. 1912.

This value is probably a little too low. If ratio (1) is rejected, the general mean of the remaining seven values becomes Cu = 63.5611, which is perhaps nearer the truth.

GOLD.

Among the early estimates of the atomic weight of gold the only ones worthy of consideration are those of Berzelius and Levol.

The earliest method adopted by Berzelius [1] was that of precipitating a solution of gold chloride by means of a weighed quantity of metallic mercury. The weight of gold thus thrown down gave the ratio between the atomic weights of the two metals. In the single experiment which Berzelius publishes, 142.9 parts of Hg precipitated 93.55 of Au. Hence if Hg = 200, Au = 196.397.

In a later investigation [2] Berzelius resorted to the analysis of potassium aurihcloride, $KCl.AuCl_3$. Weighed quantities of this salt were ignited in hydrogen; the resulting gold and potassium chloride were separated by means of water, and both were collected and estimated. The loss of weight upon ignition was, of course, chlorine. As the salt could not be perfectly dried without loss of chlorine, the atomic weight under investigation must be determined by the ratio between the KCl and the Au. If we reduce to a common standard, and compare with 100 parts of KCl, the equivalent amounts of gold will be those which I give in the last of the subjoined columns:

$KAuCl_4$.	*KCl.*	*Au.*	*Ratio.*
4.1445	.8185	2.159	263.775
2.2495	.44425	1.172	263.815
5.1300	1.01375	2.67225	263.600
3.4130	.674	1.77725	263.687
4.19975	.8295	2.188	263.773
			Mean, 263.730±.026

Hence Au = 196.63.

Still a third series of experiments by Berzelius [3] may be included here. In order to establish the atomic weight of phosphorus he employed that substance to precipitate gold from a solution of gold chloride in excess. Between the weight of phosphorus taken and the weight of gold obtained it was easy to fix a ratio. Since the atomic weight of phosphorus has been better established by other methods, we may properly reverse this ratio and apply it to our discussion of gold. One hundred parts of P precipitate the quantities of Au given in the third column:

P.	*Au.*	
0.829	8.714	1051.15
.754	7.930	1051.73
		Mean, 1051.44±.196

Hence, if P = 31, Au = 195.568.

Levol's [4] estimation of the atomic weight under consideration can hardly have much value. A weighed quantity of gold was converted in a flask into $AuCl_3$. This was reduced by a stream of sulphur dioxide, and the resulting sulphuric acid was determined as $BaSO_4$. One gramme of gold gave 1.782 grm. $BaSO_4$. Hence Au = 196.49.

All these values may be neglected as worthless except that derived from Berzelius' $KAuCl_4$ series.

In 1886 Krüss [5] published the first of the recent determinations of the atomic weight under consideration, several distinct methods being recorded. First, in a solution of pure auric chloride the gold was precipitated by means of aqueous sulphurous acid. In the filtrate from the gold the chlorine was thrown down as silver chloride, and thus the ratio Au : 3AgCl

[1] Poggend. Annalen, 8, 177.
[2] Lehrbuch, 5 Aufl., 3, 1212.
[3] Lehrbuch, 5 Aufl., 3, 1188.
[4] Ann. Chim. Phys. (3), 30, 355. 1850.
[5] Untersuchungen über das Atomgewicht des Goldes. München, 1886. 112 pp., 8vo.

was measured. I subjoin Krüss' weights, together with a third column giving the gold equivalent to 100 parts of silver chloride:

Au.	*AgCl.*	*Ratio.*
7.72076	16.84737	45.828
5.68290	12.40425	45.814
3.24773	7.08667	45.828
4.49167	9.80475	45.811
3.47949	7.59300	45.825
3.26836	7.13132	45.832
5.16181	11.26524	45.821
4.86044	10.60431	45.834
		Mean, 45.824±.0020

Hence Au = 197.05.

The remainder of Krüss' determinations were made with potassium auribromide, $KAuBr_4$, and with this salt several ratios were measured. The salt was prepared from pure materials, repeatedly recrystallized under precautions to exclude access of atmospheric dust, and dried over phosphorus pentoxide. First, its percentage of gold was determined, sometimes by reduction with sulphurous acid, sometimes by heating in a stream of hydrogen. For this ratio the weights and percentages are as follows, the experiments being numbered for further reference, and the reducing agent being indicated:

	$KAuBr_4$.	*Au.*	*Per cent.*
1. SO_2	10.64821	3.77753	35.476
2. SO_2	4.71974	1.67330	35.453
3. H	7.05762	2.50122	35.440
4. H	4.49558	1.59434	35.465
5. SO_2	8.72302	3.09448	35.475
6. SO_2	7.66932	2.71860	35.448
7. SO_2	7.15498	2.53695	35.457
8. H	12.26334	4.34997	35.471
9. H	7.10342	2.51919	35.465
			Mean, 35.461±.0028

Hence Au = 197.14.

In five of the foregoing experiments the reductions were effected with sulphurous acid; and in these, after filtering off the gold, the bromine was thrown down and weighed as silver bromide. This, in comparison with the gold, gives the ratio Au : 4AgBr : : 100 : *x*:

	Au.	*4AgBr.*	*Ratio.*
1	3.77753	14.39542	381.080
2	1.67330	6.37952	381.254
5	3.09448	11.78993	380.999
6	2.71860	10.35902	381.042
7	2.53695	9.66117	380.731
			Mean, 381.021±.057

Hence Au : AgBr : : 100 : 95.255±.0142, and Au = 197.16.

In the remaining experiments, Nos. 3, 4, 8, and 9, the $KAuBr_4$ was reduced in a stream of hydrogen, the loss of weight, 3 Br, being noted. In the residue the gold was determined, as noted above, and the KBr was also collected and weighed. The weights were as follows:

	Au.	*Loss, 3 Br.*	*KBr.*
3	2.50122	3.04422	1.51090
4	1.59434	1.93937	.96243
8	4.34997	5.29316	2.62700
9	2.51919	3.06534	1.52153

From these data we obtain two more ratios, viz, Au : Br_3 :: 100 : *x*, and Au : KBr : : 100 : *x*, thus:

	3 Br.	*Au:KBr.*
3	121.710	60.405
4	121.641	60.365
8	121.683	60.391
9	121.680	60.398
	Mean, 121.678±.0100	Mean, 60.390±.0059

Hence Au = 197.05, and 197.08.

From all the ratios, taken together, Krüss deduces a final value of Au = 197.13, if O = 16. It is obviously possible to derive still other ratios from the results given, but to do so would be to depart unnecessarily from the author's methods as stated by himself.

Thorpe and Laurie,[1] whose work appeared shortly after that of Krüss, also made use of the salt $KAuBr_4$, but, on account of difficulty in drying it without change, they did not weigh it directly. After proving the constancy in it of the ratio Au : KBr, even after repeated crystallizations, they adopted the following method: The unweighed salt was heated with gradual increase of temperature, up to about 160°, for several hours, and afterwards more strongly over a small Bunsen flame. This was done in a porcelain crucible, tared by another in weighing, which latter was treated in precisely the same way. The residue, KBr + Au, was weighed, the KBr dissolved out, and the gold then weighed separately. The weight of KBr was taken by difference. The ratio Au : KBr : : 100 : x appears in a third column:

Au.	*KBr.*	*Ratio.*
6.19001	3.73440	60.329
4.76957	2.87715	60.323
4.14050	2.49822	60.336
3.60344	2.17440	60.342
3.67963	2.21978	60.326
4.57757	2.76195	60.337
5.36659	3.23821	60.326
5.16406	3.11533	60.327
		Mean, 60.331 ± .0016

Hence Au = 197.28.

This mean combines with Krüss's thus:

Kruss	60.390 ± .0059
Thorpe and Laurie	60.331 ± .0016
General mean	60.338 ± .0015

The potassium bromide of the previous experiments was next titrated with a solution of pure silver by Stas's method, the operation being performed in red light. Thus we get the following data for the ratio Ag : Au : : 100 : x, using the weights of gold already obtained:

Ag.	*Au.*	*Ratio.*
3.38451	6.19001	182.893
2.60896	4.76957	182.813
2.28830	4.18266	182.786
2.26415	4.14050	182.868
1.97147	3.60344	182.775
2.01292	3.67963	182.801
2.50334	4.57757	182.863
2.93608	5.36659	182.780
2.82401	5.16406	182.865
		Mean, 182.827 ± .0101

Hence Au = 197.24.

Finally, in eight of these experiments, the silver bromide formed during titration was collected and weighed, giving values for the ratio Au : AgBr : : 100 : x, as follows:

Au.	*AgBr.*	*Ratio.*
6.19001	5.89199	95.186
4.76957	4.54261	95.242
4.18266	3.98288	95.224
4.14050	3.94309	95.232
3.60344	3.43015	95.191
3.67963	3.50207	95.175
4.57757	4.35736	95.189
5.36659	5.11045	95.227
		Mean, 95.208 ± .0061
		Krüss found, 95.255 ± .0142
		General mean, 95.222 ± .0056

From Thorpe and Laurie's mean, Au = 197.25.

[1] Journ. Chem. Soc., 51, 565. 1887.

From the second and third of the ratios measured by Thorpe and Laurie an independent value for the ratio Ag : Br may be computed. It becomes 100 : 74.072, which agrees fairly with the direct determinations made by other chemists. Similarly, the ratios Ag : KBr and AgBr : KBr may be calculated, giving additional checks upon the accuracy of the manipulation, though not upon the purity of the original material studied.

Thorpe and Laurie suggest objections to the work done by Krüss, on the ground that the salt $KAuBr_4$ can not be completely dried without loss of bromine. This suggestion led to a controversy between them and Krüss, which in effect was briefly as follows:

First, Krüss [1] urges that the potassium auribromide ordinarily contains traces of free gold, not belonging to the salt, produced by the reducing action of dust particles taken up from the air. He applies a correction for this supposed free gold to the determinations made by Thorpe and Laurie, and thus brings their results into harmony with his own. To this argument Thorpe and Laurie [2] reply, somewhat in detail, stating that the error indicated was guarded against by them, and that they had dissolved quantities of from 8 to 19 grammes of the auribromide without a trace of free gold becoming visible. A final note in defense of his work was published by Krüss a little later.[3]

In 1889 an elaborate set of determinations of this constant was published by Mallet,[4] whose experiments are classified into seven distinct series. First, a neutral solution of auric chloride was prepared, which was weighed off in two approximately equal portions. In one of these the gold was precipitated by pure sulphurous acid, collected, washed, dried, ignited in a Sprengel vacuum, and weighed. To the second portion a solution containing a known weight of pure silver was added. After filtering, with all due precautions, the silver remaining in the filtrate was determined by titration with a weighed solution of pure hydrobromic acid. We have thus a weight of gold, and the weight of silver needed to precipitate the three atoms of chlorine combined with it; in other words, the ratio 3Ag : Au : : 100 : x. All weights in this and the subsequent series are reduced to a vacuum, and all weighings were made against corresponding tares:

Au.	*Ag.*	*Ratio.*
7.6075	12.4875	60.921
8.4212	13.8280	60.900
6.9407	11.3973	60.898
3.3682	5.5286	60.923
2.8244	4.6371	60.909
		Mean, 60.910±.0034

Hence Ag : Au : : 100 : 182.730±.0102, and Au=197.13.

The second series of determinations was essentially like the first, except that auric bromide was taken instead of the chloride. The ratio measured, 3Ag : Au, is precisely the same as before Results as follows:

Au.	*Ag.*	*Ratio.*
8.2345	13.5149	60.929
7.6901	12.6251	60.911
10.5233	17.2666	60.945
2.7498	4.5141	60.916
3.5620	5.8471	60.919
3.9081	6.4129	60.941
		Mean, 60.927±.0038

Hence Ag : Au : : 100 : 182.781±.0114, and Au=197.18.

In the third series of experiments the salt $KAuBr_4$ was taken, purified by five recrystallizations. The solution of this was weighed out into nearly equal parts, the gold being measured as in the two preceding series in one portion, and the bromine thrown down by a standard silver solution as before. This gives the ratio 4Ag : Au : : 100 : x.

[1] Ber. Deutsch. chem. Gessell., 20, 2365. 1887.
[2] Berichte, 20, 3036, and Journ. Chem. Soc., 51, 866. 1887.
[3] Berichte, 21, 126. 1888.
[4] Philosophical Transactions, 180, 395. 1889.

Au.	*Ag.*	*Ratio.*
5.7048	12.4851	45.693
7.9612	17.4193	45.693
2.4455	5.3513	45.699
4.1632	9.1153	45.673
		Mean, 45.689±.0040

Hence Ag : Au : : 100 : 182.756±.0160, and Au=197.16.

The fifth series of determinations, which for present purposes naturally precedes the fourth, was electrolytic in character, gold and sliver being simultaneously precipitated by the same current. The gold was in solution as potassium aurocyanide, and the silver in the form of potassium silver cyanide. The equivalent weights of the two metals, thrown down in the same time, were as follows, giving directly the ratio Ag : Au : : 100 : x:

Au.	*Ag.*	*Ratio.*
5.2721	2.8849	182.748
6.3088	3.4487	182.933
4.2770	2.3393	182.832
3.5123	1.9223	182.713
3.6804	2.0132	182.814
		Mean, 182.808±.0256

Hence Au=197.22.

This mean may be combined with the preceding means, and also with the determination of the same ratio by Thorpe and Laurie, thus:

Thorpe and Laurie	182.827±.0101
Mallet, chloride series	182.730±.0102
Mallet, bromide series	182.781±.0114
Mallet, $KAuBr_4$ series	182.756±.0160
Mallet, electrolytic	182.808±.0256
General mean	182.778±.0055

In Mallet's fourth series a radically new method was employed. Trimethyl-ammonium aurichloride, $N(CH_3)_3HAuCl_4$, was decomposed by heat, and the residual gold was determined. In order to avoid loss by spattering, the salt was heated in a crucible under a layer of fine siliceous sand of known weight. Several crops of crystals of the salt were studied, as a check against impurities, but all gave concordant values.

Salt.	*Residual Au.*	*Per cent Au.*
14.9072	7.3754	49.475
15.5263	7.6831	49.484
10.4523	5.1712	49.474
6.5912	3.2603	49.464
5.5744	2.7579	49.474
		Mean, 49.474±.0021

Hence Au=197.73.

In his sixth and seventh series Mallet sought to establish, by direct measurement, the ratio between hydrogen and gold. In their experimental details his methods are somewhat elaborate, and only the processes, in the most general way, can be indicated here. First, gold was precipitated electrolytically from a solution of potassium aurocyanide, and its weight was compared with that of the amount of hydrogen simultaneously liberated in a voltameter by the same current in the same time. The hydrogen was measured, and its weight was then computed from its density. The volumes are given, of course, at 0° and 760 mm.

Wt. Au.	*Vol. H, cc.*	*Wt. H.*
4.0472	228.64	0.0205483
4.0226	227.03	.0204046
4.0955	231.55	.0208103

These data, with the weight of one litre of hydrogen taken as 0.89872 gramme, give the subjoined values in the ratio H : Au : : 1 : x.

196. 960
197. 151
196. 805

Mean, 196. 972±. 0675

In the last series of experiments a known quantity of metallic zinc was dissolved in dilute sulphuric acid, and the amount of hydrogen evolved was measured. Then a solution of pure auric chloride or bromide was treated with a definite weight of the same zinc, and the quantity of gold thrown down was determined. The zinc itself was purified by fractional distillation in a Sprengel vacuum. From these data the ratio 3H : Au was computed by direct comparison of the weight of gold and that of the liberated hydrogen. The results were as follows:

Wt. Au.	*Vol. H, cc.*	*Wt. H.*
10. 3512	1756. 10	. 157824
8. 2525	1400. 38	. 125857
8. 1004	1374. 87	. 123565
3. 2913	558. 64	. 050206
3. 4835	590. 93	. 053109
3. 6421	618. 11	. 055551

Hence for the ratio 3H : Au : : 1 : x we have:

65. 587	65. 556
65. 571	65. 593
65. 557	65. 563

Mean, 65. 571±. 00436

And H : Au : : 1 : 196.713±. 0131. This, combined with the value found in the preceding series, gives a general mean of 196.722±.0129.

The ratios available for gold are now as follows:

(1) KCl : Au :: 100 : 263.730±0. 26
(2) 3AgCl : Au :: 100 : 458.24±0. 020
(3) $KAuBr_4$: Au :: 100 : 35.461±0. 028
(4) Au : AgBr :: 100 : 95.222±0. 056
(5) Au : 3Br :: 100 : 121.678±0. 100
(6) Au: KBr :: 100 : 60.338±0. 015
(7) Ag : Au :: 100 : 182.778±00. 55
(8) $NC_3H_{10}AuCl_4$: Au :: 100 : 49.474±0. 021
(9) H : Au :: 1 : 196.722±0. 129

The antecedent atomic weights are—

Ag=107. 880 ±. 00016
Cl = 35. 4605±. 00011
Br= 79. 9228±. 00015
N=14. 0081±. 00008
K=39. 0795±. 00011
C =12. 0025±. 00019
H=1. 0078±. 00001

Hence

From ratio—

1	Au=196. 632±. 0194
5	197. 052±. 0115
2	197. 053±. 0086
3	197. 137±. 0178
7	197. 182±. 0059
4	197. 226±. 0128
6	197. 253±. 0049
8	197. 731±. 0117
9	198. 256±. 0130
General mean	Au=197. 209±. 0029

Although this final value is not altogether satisfactory, it seems probable that the atomic weight of gold is not far from Au = 197.2.

The ninth or last value in the foregoing series represents Mallet's ratio between gold and hydrogen, and is peculiarly instructive. In Mallet's paper the several ratios determined were discussed upon the basis of O = 15.96, referred to hydrogen as unity. This, on the oxygen scale, is equivalent to H = 1.0025. On that basis the determination in question agreed well with the others; but with H = 1.0078, the present value, it is enormously raised. The former agreement between the several series of gold values was therefore only apparent, and shows that concordance among determinations may be only coincidence, and no real proof of accuracy. It is probable, furthermore, that direct comparisons of metals with hydrogen cannot give good measurements of atomic weights, for several reasons. First, it is not possible to be certain that every trace of hydrogen has been collected and measured, and any loss tends to raise the apparent atomic weight of the metal studied; secondly, the weight of the hydrogen is computed from its volume, and a slight change in the factors used in reduction of the observations may make a considerable difference in the final result. These uncertainties exist in all determinations of atomic weights hitherto made by the hydrogen method.

CALCIUM.

Much of the older work on the atomic weight of calcium, including the earliest determinations by Berzelius, may be disregarded as having no present value. Baup's [1] analyses of organic salts of calcium are interesting, but carry no weight now. They led to the value Ca = 39.98. As for Salvétat's [2] determination, that was merely given as a statement of results, without such details as would make his work available for discussion.

An important factor in measuring the atomic weight of calcium is the composition of calcium carbonate, as determined by several investigators. This will be considered first, and the determinations based upon other calcium compounds follow later.

In 1842 Dumas [3] made three ignitions of Iceland spar, and determined the percentages of carbon dioxide driven off and of lime remaining. The impurities of the material were also determined, the correction for them applied, and the weighings reduced to a vacuum. His figures are as follows:

$CaCO_3$.	CaO.	*Per cent.*
49.916	28.016	56.12
50.497	28.305	56.04
64.508	36.167	56.06
		Mean, 56.073 ± .016

Hence, Ca = 40.169.

About this same time Erdmann and Marchand [4] began their researches upon the same subject. Two ignitions of spar, containing 0.04 per cent of impurity, gave, respectively, 56.09 and 56.18 per cent of residue; but these results are not exact enough for us to consider further. Four other results obtained with artificial calcium carbonate are more noteworthy. The carbonate was precipitated from a solution of pure calcium chloride by ammonium carbonate, was washed thoroughly with hot water, and dried at a temperature of 180°. With this preparation the following percentages of lime were obtained:

56.03	56.00
55.98	55.99

Mean, 56.00 ± .007

Hence, Ca = 40.003.

It was subsequently shown by Berzelius that calcium carbonate prepared by this method retains traces of water even at 200°, and that minute quantities of chloride are also held by it. These sources of error are, however, in opposite directions, since one would tend to diminish and the other to increase the weight of residue.

[1] Bull. Universelle des Sciences de Genève, 39, 347. 1842.
[2] Compt. Rend., 17, 318. 1843.
[3] Compt. Rend., 14, 547. 1842.
[4] Journ. prakt. Chem., 26, 472. 1842.

In the same paper there are also two direct estimations of carbonic acid in pure Iceland spar, which correspond to the following percentages of lime:

56.00
56.02

Mean, 56.01±.007

In a still later paper[1] the same investigators give another series of results based upon the ignition of Iceland spar. The impurities were carefully estimated, and the percentages of lime are suitably corrected:

$CaCO_3$.	CaO.	*Per cent.*
4.2134	2.3594	55.997
15.1385	8.4810	56.022
23.5503	13.1958	56.031
23.6390	13.2456	56.032
42.0295	23.5533	56.044
49.7007	27.8536	56.042

Mean, 56.028±.0047

Hence, Ca=40.067.

Six years later Erdmann and Marchand[2] published one more result upon the ignition of calcium carbonate. They found that the compound began giving off carbon dioxide below the temperature at which their previous samples had been dried, or about 200°, and that, on the other hand, traces of the dioxide were retained by the lime after ignition. These two errors do not compensate each other, since both tend to raise the percentage of lime. In the one experiment now under consideration these errors were accurately estimated, and the needful corrections were applied to the final result. The percentage of residual lime in this case was 55.998. This agrees tolerably well with the figures found in the direct estimation of carbonic acid, and, if combined with those two, gives a mean for all three of 56.006±.0043.

Hence, Ca=40.017.

Herzfeld,[3] in his determinations of atomic weight, made use of artificial calcium carbonate. The lime was prepared by ignition of the oxalate, and then converted into bicarbonate by treatment with solid carbon dioxide and water under pressure. By heating in a silver dish the bicarbonate was converted into the normal salt, which was weighed, and then ignited at a temperature of 1,300°–1,400°. The data are as follows:

$CaCO_3$	CaO.	*Per cent.*
3.9772	2.2268	55.989
2.3614	1.3218	55.975
3.2966	1.8456	55.985

Mean, 55.983±.0028

Hence, Ca=39.965.

Hinrichsen,[4] in his two separate communications, gives analyses of spar from two distinct localities, namely, Iceland and the Crimea. In each case very small quantities of impurity were present, which were carefully determined and corrected for. The spar, previously freed from all traces of moisture, was ignited in an electric furnace, at a temperature between 1,200° and 1,400°. The results obtained, with all corrections applied and vacuum weights, are subjoined:

First series.

$CaCO_3$	CaO.	*Per cent.*
30.72157	17.22354	56.0633
32.77791	18.375587	56.0617
34.45625	19.31608	56.0623
33.36885	18.70723	56.0620

[1] Journ. prakt. Chem., 31, 269. 1844.
[2] Journ. prakt. Chem., 50, 237. 1850.
[3] Zeitschr. Ver. Rübenzucker Industrie, 47, 497. 1897. Partly reproduced in Ber., 34, 559. 1904.
[4] Zeitschr. physikal. Chem., 39, 311, 1901; and 40, 747. 1902.

Second series.

$CaCO_3$.	CaO.	*Per cent.*
31. 20762	17. 49526	59. 0608
22. 00588	12. 33642	56. 0602

Mean of both series as one, 56. 0617±.0003

Hence, Ca=40.144.

Combining all these determinations, we have for the percentage of CaO from $CaCO_3$:

Dumas	56. 073 ±. 016
Erdmann and Marchand, 1	56. 000 ±. 007
Erdmann and Marchand, 2	56. 028 ±. 0047
Erdmann and Marchand, 3	56. 006 ±. 0043
Herzfeld	55. 983 ±. 0028
Hinrichsen	56. 0617±. 0003
General mean	56. 0603±. 0003

The effect of this combination is practically to discard all of the determinations except that of Hinrichsen. Herzfeld's figures are certainly too low, and probably because of undetermined impurity in his artificial carbonate. The extreme difficulty of preparing absolutely pure compounds of calcium is well known.[1]

In the earliest of the three papers by Erdmann and Marchand there is also given a series of determinations of the ratio between calcium carbonate and sulphate. Pure Iceland spar was carefully converted into calcium sulphate, and the gain in weight noted. One hundred parts of spar gave of sulphate:

136. 07 136. 02
136. 06 136. 06

Mean, 136. 0525±. 0071

Hence Ca=40.025.

In 1843 the atomic weight of calcium was redetermined by Berzelius,[2] who investigated the ratio between lime and calcium sulphate. The calcium was first precipitated from a pure solution of nitrate by means of ammonium carbonate, and the thoroughly washed precipitate was dried and strongly ignited in order to obtain lime wholly free from extraneous matter. This lime was then, with suitable precautions, treated with sulphuric acid, and the resulting sulphate was weighed. Correction was applied for the trace of solid impurity contained in the acid, but not for the weighing in air. The figures in the last column represent the percentage of weight gained by the lime upon conversion into sulphate:

CaO.	SO_3.	*Per cent gained.*
1. 80425	2. 56735	142. 295
2. 50400	3. 57050	142. 592
3. 90000	5. 55140	142. 343
3. 04250	4. 32650	142. 202
3. 45900	4. 93140	142. 567

Mean, 142. 3998±. 0518

Hence Ca=40.225.

The atomic weight of calcium has been several times computed from analyses of the chloride. The earliest determination by Berzelius [3] was based upon this compound, and Marignac [4] also used it in some provisional experiments, to which, however, he assigns little importance. They gave values for Ca far in excess of the truth. Dumas [5] also published a series of determinations of more than questionable value. Supposedly pure calcium chloride was first ignited in a stream of dry hydrochloric acid, and the solution of this salt was afterwards titrated with a silver solution in the usual way. The $CaCl_2$ proportional to 100 parts of Ag is given in a third column:

[1] See Stas, Oeuvres Complètes, 3, 337.
[2] Journ. prakt. Chem., 31, 263. Ann. Chem. Pharm., 46, 241.
[3] Poggend. Annalen, 8, 189.
[4] Oeuvres Complètes, 1, 90.
[5] Ann. Chim. Phys. (3), 55, 129. 1859. Ann. Chem. Pharm., 113, 34.

$CaCl_2$.	Ag.	Ratio.
2.738	5.309	51.573
2.436	4.731	51.490
1.859	3.617	51.396
2.771	5.3885	51.424
2.240	4.3585	51.394
		Mean, 51.4554±.0230

Hence Ca=40.099.

Better results were obtained by Richards.[1] Calcium chloride, purified by repeated crystallizations, and fused in a stream of nitrogen, was precipitated by a solution of silver, and the silver chloride so produced was weighed. The data, with vacuum weights, are subjoined:

$CaCl_2$	AgCl	Ratio
1.56454	4.0409	38.7177
3.57630	9.2361	38.7209
3.59281	9.2788	38.7206
5.00880	12.9364	38.7187
9.00246	23.2506	38.7197
		Mean, 38.7195±.0004

Hence Ca=40.080.

The ratio between calcium chloride and silver, previously determined by Dumas, has also been measured by Richards and Hönigschmid,[2] using the recognized Harvard methods.

Their weights, reduced to a vacuum, and the usual ratio follow:

Ag.	$CaCl_2$	Ratio.
8.94908	4.60350	51.4410
9.37780	4.82401	51.4407
9.36688	4.81846	51.4415
10.29911	5.29799	51.4412
10.50832	4.40550	51.4402
10.19715	5.24539	51.4398
10.38328	5.34110	51.4394
		Mean, 51.4405±.0002

Hence Ca=40.067.

It is not necessary to combine Dumas' determination with this, for its high probable error rejects it. Its influence in combination with the new determinations affects only the fifth decimal place.

In another memoir Richards and Hönigschmid [3] report determinations based on analyses of calcium bromide. Two series are given, for two ratios, with vacuum weights, as follows:

First, for the ratio $2Ag : CaBr_2 :: 100 : x$.

Ag.	$CaBr_2$.	Ratio.
4.54252	4.20860	92.6490
4.95025	4.58644	92.6507
5.77301	5.34866	92.6491
7.81126	7.23724	92.6514
5.04779	4.67673	92.6491
8.00455	7.41636	92.6518
		Mean, 92.6502±.00043

Hence, Ca=40.056.

Second, for the ratio $2AgBr_2 : CaBr_2 :: 100 : x$.

AgBr.	$CaBr_2$.	Ratio.
19.13778	10.18591	53.2241
14.88810	7.92400	53.2237
12.73961	6.78048	53.2236
12.13702	6.45970	53.2231
11.18684	5.95390	53.2225
9.69513	5.15998	53.2225
		Mean, 53.2232±.00018

Hence, Ca=40.064.

[1] Journ. Amer. Chem. Soc., 24, 374. 1902. [2] Journ. Amer. Chem. Soc., 33, 128. 1911. [3] Journ. Amer. Chem. Soc., 32, 1577. 1910.

These bromide ratios also give the cross ratio Ag: Br::100: 74.079.

The determinations of the atomic weight of calcium by Oechsner de Coninck were published in two short notes, without adequate details. In his first note [1] he gives analyses of calcium formate in which, by simple ignition, the proportion of calcium oxide was determined. The data are as follows:

$CaC_2H_2O_4$	CaO.	*Per cent CaO.*
0.7123	0.3074	43.156
.2374	.1021	43.008
.891	.3826	42.941
2.8493	1.2254	43.007
		Mean, 43.028±.0307

Hence, Ca = 39.904.

There is also a single analysis of calcium carbonate, of no value.

The second note [2] by Oechsner de Coninck deals with the conversion of calcium carbonate into sulphate. His weights and the corresponding ratio are as follows:

$CaCO_3$.	$CaSO_4$.	*Ratio.*
0.3300	0.4486	135.939
.2640	.3590	135.985
.3630	.4935	135.950
.2541	.3454	135.931
.1524	.2072	135.958
		Mean, 135.953±.0063

Hence, Ca = 40.303.

For the same ratio Erdmann and Marchand found the value 136.0525±.0071. The two series combined give a general mean of 135.999±.0043.

There are now eight independent ratios from which to compute the atomic weight of calcium, as follows:

(1) $CaCO_3 : CaO :: 100 : 56.0603 \pm .0003$.
(2) $CaO : SO_3 :: 100 : 142.3998 \pm .0518$.
(3) $CaCO_3 : CaSO_4 :: 100 : 135.999 \pm .0043$.
(4) $CaC_2H_2O_4 : CaO :: 100 : 43.028 \pm .0307$.
(5) $2Ag : CaCl_2 :: 100 : 51.4405 \pm .0002$.
(6) $2AgCl : CaCl_2 :: 100 : 38.7195 \pm .0004$.
(7) $2Ag : CaBr_2 :: 100 : 92.6502 \pm .00043$.
(8) $2AgBr : CaBr_2 :: 100 : 53.2232 \pm .00018$.

To reduce these ratios we have—

Ag=107.880±.00016 Br=79.9228±.00015
Cl=35.4605±.00011 S=32.0650±.00012
C=12.0025±.00019

Hence,

From ratio—	
4	Ca=39.9040±.0500
7	40.0564±.0010
8	40.0639±.00073
5	40.0670±.00042
6	40.0804±.0013
1	40.1404±.00053
3	40.1722±.0122
2	40.2254±.0200
General mean	Ca=40.0902±.00028

Ratios 2, 3, and 4 are evidently worthless. Their rejection, however, changes the general mean by only 0.0001. In short, they reject themselves.

[1] Compt. Rend., 153, 1479. 1911.

[2] Bull. Acad. Belg., 1913, 222.

STRONTIUM.

The ratios which fix the atomic weight of strontium resemble in general terms those relating to barium, only they are fewer in number and represent a smaller amount of work. The early experiments of Stromeyer,[1] who measured the volume of CO_2 evolved from a known weight of strontium carbonate, are hardly available for the present discussion. So, also, we may exclude the determination by Salvétat,[2] who neglected to publish sufficient details.

Taking the ratio between strontium chloride and silver first in order, we have series of figures by Pelouze, Dumas, Marignac, Richards, and Thorpe and Francis. Pelouze[3] employed the volumetric method to be described under barium, and in two experiments obtained the subjoined results. In another column I append the ratio between $SrCl_2$ and 100 parts of silver:

$SrCl_2$.	*Ag.*	*Ratio.*
1.480	2.014	73.486
2.210	2.008	73.471
		Mean, 73.4781 ± .0050

Hence, Sr = 87.615.

Dumas,[4] by the same general method, made sets of experiments with three samples of chloride which had previously been fused in a current of dry hydrochloric acid. His results, expressed in the usual way, are as follows:

Series A.

$SrCl_2$.	*Ag.*	*Ratio.*
3.137	4.280	73.2944
1.982	2.705	73.2717
3.041	4.142	73.4186
3.099	4.219	73.4534
		Mean, 73.3595

Series B.

SrCl.	*Ag.*	*Ratio.*
3.356	4.574	73.3713
6.3645	8.667	73.4327
7.131	9.712	73.4246
		Mean, 73.4095

Series C.

$SrCl_2$.	*Ag.*	*Ratio.*
7.213	9.811	73.5195
2.206	3.006	73.3866
4.268	5.816	73.5529
4.018	5.477	73.3613
		Mean, 73.4551
		Mean of all as one series, 73.4079 ± .0170

Hence, Sr = 87.464.

The foregoing determinations were followed by the work of Richards,[5] who fused his strontium chloride in a stream of gaseous hydrochloric acid and nitrogen, and adopted all of the precautions relative to the solubility of silver chloride which modern experience has shown to be necessary. The results, with vacuum weights, follow:

$SrCl_2$.	*Ag.*	*Ratio.*
4.2516	5.7864	73.476
2.4019	3.2688	73.480
3.5184	4.7886	73.475
3.0264	4.1189	73.476
		Mean, 73.4767 ± .0008

Hence, Sr = 87.613.

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[1] Schweigg. Journ., 19, 228. 1816.
[2] Compt. Rend., 17, 318. 1843.
[3] Compt. Rend., 20, 1047. 1845.
[4] Ann. Chim. Phys. (3), 55, 29. 1859. Ann. Chem. Pharm., 113, 34.
[5] Proc. Amer. Acad., 40,603. 1905. Three of the determinations were made by H. G. Parker.

Thorpe and Francis [1] determined two of the chloride ratios, as follows:
First. The ratio $2Ag : SrCl_2$:

$SrCl_2$.	Ag.	Ratio.
1.64759	2.24203	73.486
1.66352	2.26356	73.491
1.53462	2.08817	73.491
1.64619	2.24011	73.487
1.76006	2.39486	73.493
1.56224	2.12572	73.492
		Mean, 73.490±.0008

Hence, Sr = 87.641.
Second. The ratio $2AgCl : SrCl_2$:

$SrCl_2$.	AgCl.	Ratio.
1.64764	2.97899	55.309
1.66357	3.00762	55.312
1.53467	2.77446	55.314
1.64624	2.97653	55.307
1.76010	2.18202	55.314
		Mean, 55.311±.0009

Hence, Sr = 87.645.
The two chloride ratios combined give Ag : Cl :: 100 : 32.867±.0026.
The four values for the silver ratio now combine as follows:

Pelouze	73.4781±.0050
Dumas	73.4079±.0170
Richards	73.4767±.0008
Thorpe and Francis	73.4900±.0008
General mean	73.4831±.00056

The foregoing figures apply to anhydrous strontium chloride. The ratio between silver and the crystallized salt, $SrCl_2.6H_2O$, was determined in two series of experiments by Marignac.[2] Five grammes of the salt were used in each estimation, and, in the second series, the water was also determined. The quantities of the chloride corresponding to 100 parts of silver are given in the last column:

Series A.

$SrCl_2.6H_2O$.	Ag.	Ratio.
5.000	4.0515	123.411
5.000	4.0495	123.472
5.000	4.0505	123.442
		Mean, 123.442

Series B.

$SrCl_2.6H_2O$	Ag.	Ratio.
5.000	4.0490	123.487
5.000	4.0500	123.457
5.000	4.0490	123.487
		Mean, 123.477

Mean of all as one series, 123.460±.0082

Hence Sr = 87.362.
From series B, by deducting Marignac's water determinations, 40.563 per cent in mean, the ratio between silver and the anhydrous chloride can be determined. The value found is $2Ag : SrCl_2$ :: 100 : 73.3907±.0065. This is so much lower than the measurements previously cited that it needs no further consideration.

[1] Proc. Roy. Soc. 83 A., 277. 1910.
[2] Arch. Sci. Phys. Nat. 1, 220. 1858. Journ. prakt Chem., 74, 216. Oeuvres Complètes, 1, 568.

Marignac also determined the ratio between strontium chloride and strontium sulphate. By direct conversion, 100 parts of the former salt gave the quantities of sulphate shown in the third column of the next table:

$SrCl_2$.	$SrSO_4$.	Ratio.
5.942	6.887	115.932
5.941	6.8855	115.949
5.942	6.884	115.927
		Mean, 115.936±.004

Hence Sr = 86.860.

The same ratio and also the corresponding ratio between bromide and sulphate have been determined by Thorpe and Francis. Their figures are as follows:

First. Ratio $SrBr_2 : SrSO_4$:

$SrBr_2$.	$SrSO_4$.	Ratio.
7.14570	5.30466	74.236
7.64281	5.67326	74.230
9.86072	7.32047	74.239
		Mean, 74.235±.0018

Hence Sr = 87.700.

Second. Ratio $SrCl_2 : SrSO_4$:

$SrCl_2$.	$SrSO_4$.	Ratio.
7.30246	8.46071	115.861
8.71628	10.09868	115.861
8.46493	9.80743	115.859
8.79502	10.18957	115.855
		Mean, 115.859±.0010

Hence Sr = 87.629.

This value for the chloride ratio, combined with that of Marignac, gives a general mean of 115.871±.00097.

Richards,[1] in his study of strontium bromide, followed pretty much the lines laid down in his work on barium. The properties of the bromide itself were carefully investigated, and its purity established beyond reasonable doubt, and then the two usual ratios were determined. First, the ratio $2Ag : SrBr_2 :: 100 : x$, by titration with standard solutions of silver. For this ratio there are three series of measurements, by varied processes, concerning which full details are given. The data obtained, with weights reduced to a vacuum, are as follows:

First series.

Wt. Ag.	Wt. $SrBr_2$.	Ratio.
1.30755	1.49962	114.689
2.10351	2.41225	114.677
2.23357	2.56153	114.683
5.3684	6.15663	114.683
		Mean, 114.683

Second series.

Wt. Ag.	Wt. $SrBr_2$.	Ratio.
1.30762	1.49962	114.683
2.10322	2.41225	114.693
4.57502	5.24727	114.694
5.3680	6.15663	114.691
		Mean, 114.690

[1] Proc. Amer. Acad., 1894, 369.

Third series.

Wt. Ag.	*Wt. $SrBr_2$.*	*Ratio.*
2.5434	2.9172	114.697
3.3957	3.8946	114.692
3.9607	4.5426	114.692
4.5750	5.2473	114.695
		Mean, 114.694

Mean of all as one series, 114.689±.0012

Hence Sr=87.607.

For the ratio, measured gravimetrically, $2AgBr : SrBr_2 :: 100 : x$, two series of determinations are given:

First series.

Wt. AgBr.	*Wt. $SrBr_2$.*	*Ratio.*
2.4415	1.6086	65.886
2.8561	1.8817	65.884
6.9337	4.5681	65.883
		Mean, 65.884

Second series.

Wt. AgBr.	*Wt. $SrBr_2$.*	*Ratio.*
2.27625	1.49962	65.881
3.66140	2.41225	65.883
3.88776	2.56153	65.887
9.34497	6.15663	65.882
		Mean, 65.883

Mean of all as one series, 65.884±.0006

Hence Sr=87.618.

From the two bromide ratios the silver bromine ratio can be calculated, with the following result: Ag : Br :: 100 : 74.077.

The two bromide ratios have been determined by Thorpe and Francis, as follows:

First. The ratio $2Ag : SrBr_2$:

$SrBr_2$.	*Ag.*	*Ratio.*
1.77884	1.55073	114.710
1.86109	1.62216	114.729
1.85254	1.61511	114.701
1.73801	1.51534	114.694
1.85787	1.61994	114.688
1.70563	1.48707	114.697
		Mean, 114.703±.0040

Hence, Sr=87.637.

Second. The ratio $2AgBr : SrBr_2$:

$SrBr_2$.	*AgBr.*	*Ratio.*
1.86112	2.82438	65.895
1.85261	2.81155	65.893
1.73807	2.63762	65.895
1.85798	2.81999	65.886
1.70571	2.58866	65.892
		Mean, 65.892±.0011

Hence, Sr=87.649.

The two bromide rations combined give Ag : Br : : 100 : 74.077±.0067.

The bromide series of Richards and Thorpe and Francis may now be combined, as follows:

First:

Ratio $2Ag$ to $SrBr_2$.

Richards	114.689±.0012
Thorpe and Francis	114.703±.0040
General mean	114.690±.00116

Second:

Ratio 2AgBr to $SrBr_2$.

Richards	65.884±.0006
Thorpe and Francis	65.892±.0011
General mean	65.8857±.00053

There are now seven ratios from which to compute the atomic weight of strontium.

(1) $2Ag : SrCl_2 :: 100 : 73.4831 \pm .00056$.
(2) $2AgCl : SrCl_2 :: 100 : 55.311 \pm .0009$.
(3) $2Ag : SrCl_2 6H_2O :: 100 : 123.460 \pm .0082$.
(4) $2Ag : SrBr_2 :: 100 : 114.690 \pm .00116$.
(5) $2AgBr : SrBr_2 :: 100 : 65.8857 \pm .00053$.
(6) $SrCl_2 : SrSO_4 :: 100 : 115.871 \pm .00097$.
(7) $SrBr_2 : SrSO_4 :: 100 : 74.235 \pm .0018$.

To reduce these ratios, we have—

Ag=107.880 ±.00016 Br=79.9228±.00015
Cl= 35.4605±.00011 S=32.0650±.00012
H=1.0078±.00001

Hence,

From ratio—	
3	Sr=87.363−.0177
6	87.506−.0097
4	87.610−.0025
5	87.625−.0020
1	87.636−.0013
2	87.645−.0027
8	87.700−.0170
General mean	Sr=87.6314−.00093

BARIUM.

For the atomic weight of barium we have a series of nine ratios, established by the labors of Berzelius, Turner, Pelouze, Struve, Marignac, Dumas, Richards, Thorpe, Gray and Ramsay, and Oechsner de Coninck. Andrews [1] and Salvétat [2] in their papers upon this subject gave no details nor weighings, and therefore their work may properly be disregarded. First in order we may consider the ratio between silver and barium chloride as determined by Pelouze, Marignac, Dumas, and Richards.

Pelouze [3] in 1845 made the three subjoined estimations of this ratio, using his well-known volumetric method. A quantity of pure silver was dissolved in nitric acid, and the amount of barium chloride needed to precipitate it was carefully ascertained. In the last column I give the quantity of barium chloride proportional to 100 parts of silver:

$BaCl_2$.	*Ag.*	*Ratio.*
3.860	4.002	96.452
5.790	6.003	96.452
2.895	3.001	96.468

Mean, 96.4573±.0036

Hence, Ba=137.195.

Essentially the same method was adopted by Marignac [4] in 1848. His experiments were made upon four samples of barium chloride, as follows: A, commercial barium chloride, purified by crystallization from water. B, the same salt, calcined, redissolved in water, the solution saturated with carbonic acid, filtered and allowed to crystallize. C, the preceding salt, washed with alcohol and again recrystallized. D, the same, again washed with alcohol. For 100 parts of silver the following quantities of chloride were required, as given in the third column.

[1] Chemical Gazette, October, 1852.
[2] Compt. Rend., 17, 318.
[3] Compt. Rend., 20, 1047. Journ. prakt. Chem., 35, 73.
[4] Arch. Sci. Phys. Nat., 8, 271. Oeuvres Complètes, 1, 219.

	Ag.	$BaCl_2$.	*Ratio.*	
A	3.4445	3.3190	96.356	
	3.7480	3.6110	96.345	Mean, 96.354
	6.3446	6.1140	96.362	
B	4.3660	4.1780	96.356	
	4.8390	4.6625	96.352	Mean, 96.354
C	6.9200	6.6680	96.358	
	5.6230	5.4185	96.363	Mean, 96.360
D	5.8435	5.6300	96.346	
	8.5750	8.2650	96.384	
	4.8225	4.6470	96.361	Mean, 96.367
	6.8460	6.5980	96.377	
			Mean, 96.360±.0024	

Hence, Ba = 136.985.

Dumas [1] employed barium chloride prepared from pure barium nitrate and took the extra precaution of fusing the salt at a red heat in a current of dry hydrochloric acid gas. Three series of experiments upon three samples of chloride gave the following results:

	Ag.	$BaCl_2$.	*Ratio.*	
A	1.8260	1.7585	96.303	
	3.9980	3.8420	96.339	
	2.2405	2.1585	96.340	Mean, 96.333
	4.1680	4.0162	96.358	
B	1.7270	1.6625	96.265	
	2.5946	2.4987	96.304	
	3.5790	3.4468	96.306	
	4.2395	4.0822	96.290	Mean, 96.290
	4.3683	4.2062	96.289	
	4.6290	4.4564	96.271	
	9.0310	8.6975	96.307	
C	2.3835	2.2957	96.316	
	4.2930	4.1372	96.371	
	4.4300	4.2662	96.303	Mean, 96.338
	4.6470	4.4764	96.329	
	5.8520	5.6397	96.372	
			Mean, 96.316±.0055	

Hence, Ba = 136.890.

The work done by Richards [2] was of a much more elaborate kind, for it involved some collateral investigations as to the effect of heat upon barium chloride, etc. Every precaution was taken to secure the spectroscopic purity of the material, which was prepared from several sources, and similar care was taken with regard to the silver. For details upon these points the original paper must be consulted. As for the titrations three methods were adopted, and a special study was made with reference to the accurate determination of the end point, in which particular the investigations of Pelouze, Marignac, and Dumas were at fault. In the first series of determinations silver was added in excess, and the latter was measured with a standard solution of hydrochloric acid. The end point was ascertained by titrating backward and forward with silver solution and acid and was taken as the mean between the two apparent end points thus observed. The results of this series, with weights reduced to a vacuum, were as follows:

Ag.	$BaCl_2$.	*Ratio.*
6.1872	5.9717	96.517
5.6580	5.4597	96.495
3.5988	3.4728	96.499
9.4010	9.0726	96.507
.7199	.6950	96.541
		Mean, 96.512±.0055

In the second series of experiments a small excess of silver was added as before, and the precipitate of silver chloride was removed by filtration. The filtrate and wash waters were concentrated to small bulk, whereupon a trace of silver chloride was obtained and taken into

[1] Ann. Chem. Pharm., 113, 22. 1860. Ann. Chim. Phys. (3), 55, 129.

[2] Proc. Amer. Acad., 29, 55. 1893.

account. The excess of silver remaining was then thrown down as silver bromide, and from the weight of the latter the silver was calculated and subtracted from the original amount:

Ag.	*$BaCl_2$.*	*Ratio.*
6.59993	6.36974	96.512
5.55229	5.36010	96.539
4.06380	3.92244	96.522
		Mean, 96.524±.0054

The third series involved mixing solutions of barium chloride and silver in as nearly as possible equivalent amounts, and then determining the actual quantities of silver and chlorine left unprecipitated. The filtrate and wash waters were divided into two portions, one-half being evaporated with hydrobromic acid and the other with silver nitrate. The small amounts of silver bromide and chloride thus obtained were determined by reduction and the use of Volhard's method:

Ag.	*$BaCl_2$.*	*Ratio.*
4.4355	4.2815	96.528
2.7440	2.6488	96.531
6.1865	5.9712	96.520
3.4023	3.2841	96.526
		Mean, 96.526±.0016

Two final experiments were carried out by Stas's method, somewhat as in the first series, with variations and greater refinement in the observation of the end point. The results were as follows:

Ag.	*$BaCl_2$.*	*Ratio.*
6.7342	6.50022	96.525
10.6023	10.23365	96.523
		Mean, 96.524±.0007

A careful study of Richards's paper will show that, although the last two experiments are probably the nest, they are not entitled to such preponderance of weight as the "probable error" here computed would give them. If all of the determinations are assigned equal weight and treated as one series, the mean becomes 96.520±.0025, but this figure is not satisfactory. The four series are unequal in merit, and that fact may be fairly recognized by combining the first and second series into one, and the third and fourth series similarly. On this basis the combination of all the data assumes the following form:

Pelouze	96.457 ±.0036
Marignac	96.360 ±.0024
Dumas	96.316 ±.0055
Richards, Series 1, 2	96.5165±.0040
Richards, Series 3, 4	96.5255±.0010
General mean	96.4947±.00086

Richards's determinations alone give Ba=137.341.

The ratio between silver and crystallized barium chloride has been fixed by Marignac.[1] The usual method was employed, and two series of experiments were made, in the second of which the water of crystallization was also determined. Five grammes of chloride were taken in each determination, to which the subjoined weights of silver correspond. The ratio to 100 parts of silver is given in the second column:

	Weight Ag.	*Ratio.*
B	4.4205	113.109
	4.4195	113.135
	4.4210	113.097
A	4.4195	113.135
	4.4200	113.122
	4.4215	113.060
		Mean, 113.110±.0079

Hence, Ba=137.094.

[1] Arch. Sci. Phys. Nat., 1, 209. 1858. Journ. prakt. Chem., 74, 212. Oeuvres Complètes, 1, 559.

The direct ratio between the chlorides of silver and barium has been measured by Berzelius, Turner, Richards, and Thorpe. Berzelius[1] found of barium chloride proportional to 100 parts of silver chloride—

72.432
72.422

Mean, 72.427

Hence, Ba = 136.713.

Turner[2] made five experiments, giving the following values for the ratio:

72.754
72.406
72.622
72.664
72.653

Mean, 72.680±.0154

Hence, Ba = 137.438.

Of these Turner regards the fourth and fifth as the best; but for present purposes it is not desirable to so discriminate.

Richards's determinations[3] fall into three series, and all are characterized by their taking into account chloride of silver recovered from the wash waters. In the first series the barium chloride was ignited at low redness in air or nitrogen; in the second series it was fused in a stream of pure hydrochloric acid; and in the third series it was not ignited at all. In the last series it was weighed in the crystallized state and the amount of anhydrous chloride was computed from the data so obtained. The data, corrected to vacuum standards, are as follows:

	AgCl.	*$BaCl_2$.*	*Ratio.*	
A	8.7673	6.3697	72.653	
	5.1979	3.7765	72.654	
	4.9342	3.5846	72.648	Mean, 72.649
	2.0765	1.5085	72.646	
	4.4271	3.2163	72.650	
B	2.09750	1.52384	72.650	
	7.37610	5.36010	72.669	Mean, 72.6563
	5.39906	3.92244	72.650	
C	8.2189	5.97123	72.6524	Mean, 72.6555
	4.5199	3.28410	72.6587	
			Mean, 72.653±.0014	

Hence, Ba = 137.361.

If we combine this with Richards's silver series, which, in mean, may be written $2Ag : BaCl_2 : : 100 : 96.525$, the cross ratio between silver and chlorine becomes $Ag : Cl : : 100 : 32.858$.

Thorpe's[4] measurements of this ratio are not important, for they were merely intended as a check upon the method he used in determining the atomic weight of radium, which involved the manipulation of very small quantities of material. His data are given here for the sake of completeness:

AgCl.	*$BaCl_2$.*	*Ratio.*
0.1578	0.1147	72.687
.2368	.1721	72.677
.0788	.0571	72.462
.0861	.0626	72.706
.0937	.0681	72.679
.1914	.1395	72.884
.1083	.0788	72.761
		Mean, 72.694±.0320

Hence, Ba = 137.479.

[1] Poggend. Annalen, 8, 177.
[2] Phil. Trans., 1829, 291.
[3] Proc. Amer. Acad. 29, 55, 1893.
[4] Proc. Roy. Soc., 80A, 298. 1908.

Assigning to Berzelius' work equal weight with that of Turner, the four series representing the ratio $2AgCl : BaCl_2$ combine as follows:

Berzelius	72.427±.0154
Turner	72.680±.0154
Richards	72.653±.0014
Thorpe	72.694±.0320
Mean,	72.650±.0014

The ratio between barium nitrate and barium sulphate has been determined only by Turner.[1] According to his experiments 100 parts of sulphate correspond to the following quantities of nitrate:

112.060
111.990
112.035

Mean, 112.028±.014

Hence, Ba = 136.317.

For the similar ratio between barium chloride and barium sulphate, there are determinations by Turner, Berzelius, Struve, Marignac, and Richards.

Turner[2] found that 100 parts of chloride ignited with sulphuric acid gave 112.19 parts of sulphate. By the common method of precipitation and filtration a lower figure was obtained, because of the slight solubility of the sulphate. This observation bears directly upon many other atomic weight determinations.

Berzelius,[3] treating barium chloride with sulphuric acid, obtained the following results in $BaSO_4$ for 100 parts of $BaCl_2$:

112.17
112.18

Mean, 112.175

Hence, Ba = 135.60.

Struve,[4] in two experiments, found—

112.0912
112.0964

Mean, 112.0938

Hence, Ba = 136.99.

Marignac's [5] three results are as follows:

$BaCl_2$.	*$BaSO_4$.*	*Ratio.*
8.520	9.543	112.007
8.519	9.544	112.032
8.520	9.542	111.995
	Mean,	112.011±.0071

Hence, Ba = 138.42.

Richards, in his work on this ratio, regards the results as of slight value, because of the occlusion of the chloride by the sulphate. This source of error he was never able to avoid entirely. Another error in the opposite direction is found in the retention of sulphuric acid by the precipitated sulphate. Eight experiments were made in two series, one set by adding sulphuric acid to a strong solution of barium chloride in a platinum crucible, the other by precipitation in the usual way. Richards gives in his published paper only the end results and the mean of his determinations; the details cited below I owe to his personal kindness. The weights are reduced to a vaccum.

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[1] Phil. Trans., 1833, 538.
[2] Phil. Trans., 1829, 291.
[3] Poggend. Annalen, 8, 177.
[4] Ann. Chem. Pharm., 80, 204. 1851.
[5] Arch. Sci. Phys. Nat., 1, 209. 1858. Journ. prakt. Chem., 74, 212. Oeuvres Completes, 1, 559.

	$BaCl_2$.	$BaSO_4$.	Ratio.
First	1.78934	2.0056	112.086
	2.07670	2.3274	112.072
	1.58311	1.7741	112.064
	3.27563	3.6712	112.076
	3.02489	3.3903	112.080
	3.87091	4.3385	112.080
Second	3.02489	3.9726	112.076
	3.87091	3.4880	112.085
			Mean, 112.077±.0017

Hence, Ba=137.283.

This mean is subject to a small correction, due to loss of chlorine on drying the chloride, which reduces it to 112.073. Omitting Turner's single determination as unimportant, and assigning to the work of Berzelius and of Struve equal weight with that of Marignac, the measurements of this ratio combine thus:

Berzelius	112.175±.0071
Struve	112.094±.0071
Marignac	112.011±.0071
Richards	112.073±.0017
General mean	112.075±.0016

In an earlier paper than the one previously cited, Richards[1] studied with great care the ratios connecting barium bromide with silver and silver bromide. The barium bromide was prepared by several distinct processes, its behavior upon dehydration and even upon fusion was studied, and its specific gravity was determined. The ratio with silver was measured by titration, a solution of hydrobromic acid being used for titrating back. The data are subjoined, with the $BaBr_2$ equivalent to 100 parts of silver stated:

$BaBr_2$.	Ag.	Ratio.
2.28760	1.66074	137.746
3.47120	2.52019	137.736
2.19940	1.59687	137.732
2.35971	1.71323	137.735
2.94207	2.13584	137.748
1.61191	1.17020	137.747
2.10633	1.52921	137.740
2.19682	2.11740	137.755
2.37290	1.72276	137.738
1.84822	1.34175	137.747
5.66647	4.11360	137.750
3.52670	2.56010	137.756
4.31690	3.13430	137.731
3.36635	2.44385	137.748
3.46347	2.51415	137.759
		Mean, 137.745±.0015

Hence, Ba=137.352.

The silver bromide in most of these determinations, and in some others, was collected and weighed in a Gooch crucible with all necessary precautions. Vacuum reductions apply to both ratios. I give in a third column the $BaBr_2$ equivalent to 100 parts of AgBr:

$BaBr_2$.	AgBr.	Ratio.
2. 28760	2. 89026	79. 149
3. 47120	4. 38635	79. 136
3. 81086	4. 81688	79. 133
2. 35971	2. 98230	79. 124
2. 94207	3. 71809	79. 129
2. 10633	2. 66191	79. 128
2. 91682	3. 68615	79. 129

[1] Proc. Amer. Acad., 28, 1. 1893.

$BaBr_2$.	$AgBr$.	Ratio.
2.37290	2.99868	79.131
1.84822	2.33530	79.143
1.90460	2.40733	79.116
5.66647	7.16120	79.127
3.52670	4.45670	79.133
2.87743	3.63644	79.127
3.46347	4.37669	79.135
		Mean, 79.132±.0015

Hence, Ba = 137.378. From the two bromide ratios combined, Ag: Br : : 100 : 74.070.

The last ratio was also determined by Thorpe,[1] incidentally to his work on the atomic weight of radium:

$BaBr_2$.	$AgBr$.	Ratio.
0.0899	0.1136	79.137
.0960	.1214	79.077
.1110	.1403	79.116
.0910	.1149	79.199
.0808	.1021	79.138
		Mean, 79.133±.0134

Hence, Ba = 137.328, in confirmation of Richards' series. On combination with the latter no noteworthy change is produced.

The determinations of the atomic weight of barium by Gray and Ramsay[2] were merely intended as a check upon the accuracy of their work on radium. Barium bromide was converted into chloride, which was afterwards reconverted into bromide. The microbalance was used, and the following weights, in milligrammes, were obtained:

$$3.50557\ BaBr_2 = 2.45668\ BaCl_2 = 3.50883\ BaBr_2.$$

Hence, there are two values for the ratio $BaBr_2 : BaCl_2 : 100 :: x$, as follows:

70.079
70.014
Mean, 70.046±.0220

These determinations are of slight importance, and so too are those of Oechsner de Coninck.[3] Barium carbonate was dissolved in nitric acid, and the liberated carbon dioxide was collected in caustic potash and weighed. The weights obtained, and the percentage of CO_2 follow:

$BaCO_3$.	CO_2.	Per cent CO_2.
1.6100	0.3587	22.280
1.7700	.3447	22.299
1.4480	.3229	22.300
1.1590	.2583	22.286
1.2275	.2738	22.305
		Mean, 22.294±.0032

Hence, Ba = 137.371.

From the following nine ratios the atomic weight of barium can now be computed:

(1) $2Ag : BaCl_2 :: 100 : 96.4947 \pm .00086$.
(2) $2AgCl : BaCl_2 :: 100 : 72.650 \pm .0014$.
(3) $2Ag : BaCl_2.2H_2O :: 100 : 113.110 \pm .0079$.
(4) $BaSO_4 : BaN_2O_6 :: 100 : 112.028 \pm .014$.
(5) $BaCl_2 : BaSO_4 :: 100 : 112.075 \pm .0016$.
(6) $2Ag : BaBr_2 :: 100 : 137.745 \pm .0015$.
(7) $2AgBr : BaBr_2 :: 100 : 79.132 \pm .0015$.
(8) $BaBr_2 : BaCl_2 :: 100 : 70.046 \pm .0220$.
(9) $BaCO_3 : CO_2 :: 100 : 22.294 \pm .0032$.

[1] Proc. Roy. Soc. 80A, 298. 1908. [2] Proc. Roy. Soc., 86A, 289. 1912. [3] Rev. Gén. Chim., 16, 245. 1913.

To reduce these ratios we have:

Ag=107.880 ±.00016 N=14.0081±.00008
Cl= 35.4605±.00011 S=35.0650±.00012
Br= 79.9228±.00015 C=12.0025±.00019
H=1.0078±.00001

Hence,

From ratio—	
4	Ba=136.317±.2705
8	137.023±.2180
3	137.094±.0171
1	137.276±.0019
5	137.308±.0314
6	137.352±.0033
2	137.353±.0041
9	137.371±.0224
7	137.378±.0056
General mean	Ba=137.308±.0015

This mean is probably too low, for the value from ratio 1 is affected by the doubtful determinations of several early investigators. That ratio, however, has the highest weight in the combination. Rejecting the first four values, the last five give a general mean of

Ba=137.358±.0023

which will be adopted in subsequent computations.

A few experiments are on record with reference to determining the atomic weight of barium from the percentage of water in the hydrated chloride. This method has been carefully investigated by Guye and Tsakalotos,[1] who conclude that the chloride in question is not suited to the purpose. Their data give Ba=139.5 approximately; while similar data by Marignac give 136.5. The subject needs no further consideration here.

RADIUM.

The early, preliminary attempts to determine the atomic weight of radium may be ignored, for they were made with confessedly impure material. In 1902 Madame Curie[2] published the first determinations of any value, basing them upon the following analyses of radium chloride. The ratio $2AgCl : RaCl_2$ is given in the third column:

$RaCl_2$.	*AgCl.*	*Ratio.*
0.09192	0.08890	103.397
.02936	.08627	103.582
.08839	.08589	102.911
		Mean, 103.297±.1349

Hence, Ra=225.21.

In the foregoing determinations the radium chloride still contained appreciable amounts of barium chloride. In a later series of determinations Madame Curie[3] used purer material, and in much larger quantities. The results obtained were as follows:

$RaCl_2$.	*AgCl.*[a]	*Ratio.*
.4052	.39054	103.768
.4020	.38784	103.651
.39335	.37944	103.666
		Mean, 103.695±.0236

Hence, Ra=226.35.

[a] Corrected for the weight of filter ash.

[1] Journ. Chim. Phys., 7, 215. 1909. Marignac's figures are discussed in the second edition of this work. See also Baker and Adlam, Journ. Chem. Soc., 99, 502.

[2] Ann. Chim. Phys. (7), 30, 140. 1903. Preliminary data in Compt. Rend., 135, 80. 1902.

[3] Compt. Rend., 145, 422. 1907.

Still more recent are the determinations by Thorpe,[1] on small quantities of material :

$RaCl_2$.	$AgCl$.	Ratio.
0.0627	0.0604	103.808
.0639	.0618	103.398
.0784	.0753	104.117
		Mean, 103.774±.1399

Hence, Ra = 226.57.

Thorpe regards his figures, however, as merely corroborative of Madame Curie's. A combination of the two series gives 103.700 for the general mean, and Ra = 226.37.

In his determinations of the atomic weight of radium, Hönigschmid had at his command the resources of the Radium Institute at Vienna, and was able to use much larger quantities of material than his predecessors. In his first memoir [2] he gives analyses of radium chloride with all modern precautions. His weights, reduced to a vacuum, and the corresponding ratios follow :

$RaCl_2$.	$AgCl$.	Ag.	Ag ratio.	AgCl ratio.
1.06167	1.02534	.....	.....	103.543
1.03300	.99751	.....	.....	103.558
1.01687	.98205	.....	.....	103.547
.99905	.96473	.72626	137.561	103.557
.98555	.95166	.71630	137.589	103.561
.97142	.93804	.70600	137.595	103.559
.60385	.58316	.....	.....	103.548
.57579	.55606	.....	.....	103.548
			Mean, 137.582±.0022	103.553±.0016

From the Ag ratio, Ra = 225.926. From the AgCl ratio, Ra = 225.946.

It is not necessary to combine the earlier determinations with these, for their high probable errors discard them.

In a second memoir by Hönigschmid [3] he reports analyses of radium bromide. First, for the ratio $2AgBr : RaBr_2 :: 100 : x$.

$RaBr_2$.	$AgBr$.	Ratio.
1.17016	1.13940	102.699
.99658	.97022	102.717
.90111	.87733	102.710
.75504	.73502	102.724
.72731	.70810	102.715
.60329	.58734	102.715
1.08458	1.05588	102.777
		Mean, 102.714±.0019.

Hence, Ra = 225.953.

Second, the ratio $2Ag : RaBr_2 :: 100 : x$.

$RaBr_2$.	Ag.	Ratio.
0.68496	0.38306	178.813
.60329	.33739	178.811
		Mean, 178.812±.0009

Hence, Ra = 225.959.

The determinations by Gray and Ramsay [4] are quite unlike those already considered. They converted radium bromide into chloride, and so sought to establish the ratio $RaBr_2 : RaCl_2 :: 100 : x$. The quantities of material used were very small, and weighed on the microbalance. The weights, in milligrammes and reduced to a vacuum, and the ratio follow:

$RaBr_2$.	$RaCl_2$.	Ratio.
2.91458	2.24144	76.904
2.91415	2.24113	76.905
1.50117	1.15474	76.923
.36910	.28400	76.944
2.85262	2.19586	76.977
2.76084	2.12492	76.966

[1] Proc. Roy. Soc., 80, A, 298. 1908.
[2] Monatsh. Chem., 33, 253. 1911.
[3] Sitzungsb. Wien. Akad., 121, Abth IIa. Nov. 1912.
[4] Proc. Roy. Soc., 86 A, 270. 1912.

$RaBr^2$.	$RaCl_2$.	Ratio.
2. 61099	2. 00988	76. 978
2. 43281	1. 87275	76. 979
2. 36062	1. 81711	76. 976
		Mean, 76. 945±. 0072

Hence, Ra = 225.860.

In his second memoir, which was later than that of Gray and Ramsay, Hönigschmid gives two determinations of the same ratio, as follows: These weights are of course in grams.

$RaBr_2$.	$RaCl_2$.	Ratio.
0. 12885	0. 09915	76. 950
. 93192	. 71712	76. 952
		Mean, 76. 951

Hence, Ra = 225.962.

If we assign this pair of values equal weight with the mean of Gray and Ramsay's determinations, the general mean becomes 76.948 ± .0050.

There are now five ratios from which to compute the atomic weight of radium.

(1) $2Ag : RaCl_2 :: 100 : 137.582 \pm .0022$.
(2) $2AgCl : RaCl_2 :: 100 : 103.553 \pm .0016$.
(3) $2Ag : RaBr_2 :: 100 : 178.812 \pm .0009$.
(4) $2AgBr : RaBr_2 :: 100 : 102.714 \pm .0019$.
(5) $RaBr_2 : RaCl_2 :: 100 : 76.948 \pm .0050$.

To reduce these we have—

Ag = 107. 880 ±. 00016
Cl = 35. 4605±. 00011
Br = 79. 9228±. 00015

Hence,

From ratio—	
5	Ra = 225. 911±. 0348
1	225. 926±. 0048
2	225. 946±. 0042
4	225. 953±. 0072
3	225. 959±. 0022
General mean	Ra = 225. 952±. 0017

LEAD.

For the atomic weight of lead we have to consider experiments made upon the oxide, chloride, bromide, nitrate, sulphate, and the metal itself. The researches of Berzelius upon the carbonate and various organic salts need not now be be considered, nor is it worth while to take into account any work of his done before the year 1818. The results obtained by Döbereiner[1] and by Longchamp[2] are also without present value.

For the exact composition of lead oxide we have to depend upon the researches of Berzelius. His experiments were made at different times through quite a number of years; but were finally summed up in the last edition of his famous "Lehrbuch."[3] In general terms his method of experiment was very simple. Perfectly pure lead oxide was heated in a current of hydrogen, and the reduced metal weighed. From his weighings I have calculated the percentages of lead thus found and given them in a third column:

Earlier results.

PbO.	Pb.	Per cent.
8. 045	7. 4675	92. 8217
14. 183	13. 165	92. 8224
10. 8645	10. 084	92. 8160
13. 1465	12. 2045	92. 8346
21. 9425	20. 3695	92. 8313
11. 159	10. 359	92. 8309

[1] Schweig. Journ., 17, 241. 1816. [2] Ann. Chim. Phys., 34, 105. 1827. [3] Bd. 3, s. 1218.

Latest.

6. 6155	6. 141	92. 8275
14. 487	13. 448	92. 8280
14. 626	13. 5775	92. 8313

Mean, 92. 8271±. 0013

Hence, Pb = 207.062.

For the synthesis of lead sulphate we have data by Berzelius, Turner, and Stas. Berzelius,[1] whose experiments were intended rather to fix the atomic weight of sulphur, dissolved in each estimation 10 grammes of pure lead in nitric acid, then treated the resulting nitrate with sulphuric acid, brought the sulphate thus formed to dryness, and weighed. One hundred parts of metal yield of $PbSO_4$:

146. 380	146. 440
146. 400	146. 458

Mean, 146. 419±. 012

Hence, Pb = 206.95.

Turner,[2] in three similar experiments, found as follows:

146. 430
146. 398
146. 375

Mean, 146. 401±. 011

Hence, Pb = 207.03.

In these results of Turner's, *absolute* weights are implied.

The results of Stas' syntheses,[3] effected after the same general method, but with variations in details, are as follows. Corrections for weighing in air were applied:

Weight Pb.	*Weight $PbSO_4$.*	*Ratio.*
141. 9925	207. 9388	146. 443
148. 016	217. 6141	146. 427
100. 000	146. 419	146. 419
200. 000	292. 864	146. 432
250. 000	366. 0525	146. 421
250. 000	366. 0575	146. 423

Mean, 146. 4275±. 0024

Hence, Pb = 206.91.

Combining, we get the subjoined result:

Berzelius	146. 419 ±. 012
Turner	146. 401 ±. 011
Stas	146. 4275±. 0024
General mean	146. 4262±. 0023

Turner, in the same paper, also gives a series of syntheses of lead sulphate, in which he starts from the oxide instead of from the metal. One hundred parts PbO, upon conversion into $PbSO_4$, gained weight as follows:

35. 84	35. 79
35. 71	35. 78
35. 84	35. 92
35. 75	

Mean, 35.804±.018

Hence, Pb = 207.623.

These figures are not wholly reliable. Numbers 1, 2, and 3 represent lead oxide contaminated with traces of nitrate. The oxide of 4, 5, and 6 contained traces of minium. Number 7 was free from these sources of error, and, therefore, deserves more consideration. The series as a whole undoubtedly gives too low a figure, and this error would tend to slightly raise the atomic weight of lead.

[1] Lehrbuch, 5th ed., 3, 1187 [2] Phil. Trans., 1833, 527–538. [3] Oeuvres Complètes, 1, 390.

Still a third series by Turner establishes the ratio between the nitrate and the sulphate, a known weight of the former being in each experiment converted into the latter. One hundred parts of sulphate represent of nitrate:

109.312
109.310
109.300
Mean, 109.307 ± .002

Hence, Pb = 204.75. This value is so low that it need not be considered further.

In all these experiments by Turner the necessary corrections were made for weighing in air.

In 1846 Marignac[1] published two sets of determinations of only moderate value. First, chlorine was conducted over weighed lead, and the amount of chlorine so formed was determined. The lead chloride was fused before weighing. The ratio to 100 Pb is given in the last column:

Pb.	*$PbCl_2$.*	*Ratio.*
20.506	27.517	134.190
16.281	21.858	134.225
25.454	34.149	134.159
		Mean, 134.191 ± .013

Hence, Pb = 207.426.

Secondly, lead chloride was precipitated by silver nitrate and the ratio between $PbCl_2$ and 2AgCl determined. The third column gives the $PbCl_2$ equivalent to 100 parts of AgCl:

$PbCl_2$.	*AgCl.*	*Ratio.*
12.534	12.911	97.080
14.052	14.506	96.870
25.533	26.399	96.720
		Mean, 96.890 ± .0704

Hence, Pb = 206.84.

For the ratio between lead chloride and silver we have first a series of results by Marignac and one experiment by Dumas. There are also later determinations to be considered in chronological order. Some old data by Turner and by Berzelius are of no present value.

Marignac,[2] applying the method used in his researches upon barium and strontium, and working with lead chloride which had been dried at 200°, obtained these results. The third column gives the ratio between $PbCl_2$ and 100 parts of Ag:

$PbCl_2$.	*Ag.*	*Ratio.*
4.9975	3.8810	128.768
4.9980	3.8835	128.698
5.0000	3.8835	128.750
5.0000	3.8860	128.667
		Mean, 128.721 ± .016

Hence, Pb = 206.81.

Dumas,[3] in his investigations, found that lead chloride retains traces of water even at 250°, and is sometimes also contaminated with oxychloride. In one estimation 8.700 grammes $PbCl_2$ saturated 6.750 of Ag. The chloride contained .009 of impurity; hence, correcting $Ag : PbCl_2 :: 100 : 128.750$. If we assign this figure equal weight with those of Marignac, we get as the mean of all 128.7266 ± .013. The sources of error indicated by Dumas, if they are really involved in this mean, would tend slightly to raise the atomic weight of lead.

The synthesis of lead nitrate, as carried out by Stas,[4] gives better results. Two series of experiments were made, with from 103 to 250 grammes of lead in each determination. The metal was dissolved in nitric acid, the solution evaporated to dryness with extreme care, and the nitrate weighed. All weighings were reduced to the vacuum standard. In series A the lead nitrate was dried in an air current at a temperature of about 155°. In series B the drying

[1] Ann. Chem. Pharm., 59, 289, and 290. 1846. Oeuvres Complètes, 1, 186.
[2] Journ. prakt. Chem., 74, 218. 1858. Oeuvres Complètes, 1, 574.
[3] Ann. Chem. Pharm., 113, 35. 1860.
[4] Oeuvres Complètes, 1, 386.

was effected in vacuo. The data are as follows, together with the ratio of nitrate to 100 parts of lead:

Series A.

Weight Pb.	*Weight PbN_2O_6.*	*Ratio.*
103.000	164.773	159.973
140.6887	225.0674	159.975
110.2672	176.408	159.982
141.9927	227.1527	159.975
148.616	237.702	159.968
123.348	198.924	159.973
		Mean, 159.9743±.0012

Series B.

Weight Pb.	*Weight PbN_2O_6.*	*Ratio.*
100.000	159.970	159.970
200.000	319.928	159,964
250.000	399.8975	159.959
250.000	399.914	159.965
		Mean, 159,9645±.0015
		Mean from both series, 159.9704±.0010

Hence, Pb = 206.796.

There is still another set of experiments upon lead nitrate, originally intended to fix the atomic weight of nitrogen, which may properly be included here. It was carried out by Anderson [1] in Svanberg's laboratory, and has also appeared under Svanberg's name. Lead nitrate was carefully ignited, and the residual oxide weighed, with the following results:

PbN_2O_6.	*PbO.*	*Per cent.*
5.19485	3.5017	67.4071
9.7244	6.5546	67.4037
9.2181	6.2134	67.4044
9.6530	6.5057	67.3957
		Mean, 67.4027±.0016

Hence, Pb = 207.35.

The direct ratio beteeen lead and silver has been roughly measured by the electrochemical experiments of Betts and Kern.[2] Lead silicofluoride was dissolved in hydrofluosilicic acid, and from the solution the lead was thrown down electrolytically, silver being simultaneously precipitated by the same current. Two series of experiments gave the following data. The ratio 2Ag : Pb : : 100 : x is stated in the third column:

First Series.

Weight Ag.	*Weight Pb.*	*Ratio.*
5.8958	5.6221	95.476
5.8958	5.6396	95.654
5.7863	5.5246	95.477
5.7863	5.5450	95.830
7.8408	7.5108	95.791
7.8408	7.5168	95.868
7.6253	7.3191	95.984
7.6253	7.3221	96.025
6.2287	5.9600	95.676
6.2287	5.9605	95.694
16.6804	15.9996	95.919
16.6804	16.0014	95.923
6.8652	6.5815	95.868
6.8652	6.5812	95.863
9.3253	8.9390	95.858
9.3253	8.9419	95.889
6.8566	6.5695	95.813
6.8754	6.5877	95.816
		Mean, 95.801±.0243

[1] Ann. Chim. Phys. (3), 9, 254. 1843.

[2] Trans. Amer. Electrochem. Soc., 6, 67.

Second Series.

Weight Ag.	*Weight Pb.*	*Ratio.*
9.0470	8.6678	95.809
9.0470	8.6663	95.792
13.4113	12.8607	95.895
13.4113	12.8558	95.858
7.2780	6.9716	95.790
7.2780	6.9755	95.844
7.2738	6.9605	95.693
7.2738	6.9698	95.821
6.5278	6.2550	95.821
6.4864	6.2168	95.844
		Mean, 95.817±.0109
		General mean of both series, 95.814±.0097

Hence, Pb = 206.73.

Baxter and Wilson [1] determined the atomic weight of lead by analyses of lead chloride, which had been previously fused in an atmosphere of gaseous hydrochloric acid. The ratio to Ag and to AgCl were both determined, and the figures obtained, with vacuum weights, are as follows:

$PbCl_2$.	*Ag.*	*AgCl.*	*Ag ratio.*	*AgCl ratio.*
4.67691	3.62987	4.82273	128.845	96.976
3.67705	2.85375	.....	128.850	.....
4.14110	3.21408	4.27016	128.842	96.978
4.56988	3.54672	.....	128.848	.....
5.12287	3.97568	5.28272	128.855	96.974
3.85844	2.99456	3.97949	128.848	96.958
4.67244	3.62628	.....	128.849	.....
3.10317	2.40837	3.19909	128.849	97.002
4.29613	3.33407	4.42982	128.856	96.982
			Mean, 128.849±.0010	96.978±.0039

From Ag ratio, Pb = 207.088.

From AgCl ratio, Pb = 207.096.

And Ag : Cl :: 100 : 32.864.

The work done upon the atomic weight of lead by Meaglia [2] is confessedly an approximation, and nothing more. Metallic lead was used to precipitate silver from a nitrate solution, and in that way the ratio Ag : Pb was determined. Two series of observations were made, with different preparations of lead. Calculated with Ag = 107.93, the following values for Pb were obtained:

1.	*2.*
206.872	206.866
206.907	206.897
206.903	206.927
206.909	206.933
206.930	206.935
206.903	
206.929	

Treating both series as one, and reducing the figures to the form of ratio adopted in this work, the mean becomes

2Ag : Pb :: 100 : 95.853±.0020.

Combined with the series by Betts and Kern, 95.814±.0097, the general mean becomes 95.850±.0019.

The same electrolytic ratio has also been measured by Pecheux,[3] who found Pb = 206.86. As no details are given this determination can not be utilized here.

Analyses of lead bromide by Baxter and Thorvaldson,[4] lead to a slightly higher value for the atomic weight of lead than Baxter and Wilson obtained from the chloride. Their corrected weights and the usual ratio follow:

[1] Proc. Amer. Acad., 43, 365. 1907. Journ. Amer. Chem. Soc., 30, 187.
[2] Thesis, University of Grenoble, 1907.
[3] Compt. Rend., 154, 1419. 1912.
[4] Journ. Amer. Chem. Soc., 37, 1020. 1915.

$PbBr_2$.	*Ag.*	*AgBr.*	*Ag ratio.*	*AgBr ratio.*
6.55858	3.85610	6.71241	170.083	97.708
4.83285	2.84126	.....	170.095	.....
5.67758	3.33787	.....	170.096	.....
6.73361	3.95874	6.89124	170.095	97.713
5.93130	3.48660	.....	170.117	.....
5.01729	2.94968	5.13400	170.096	97.727
5.89902	3.46730	.....	170.133	.....
7.71526	4.53498	7.89526	170.128	97.720
7.40244	4.35157	.....	170.110	.....
7.01144	4.12154	7.17470	170.117	97.725
6.91460	4.06484	7.07672	170.108	97.709
8.12623	4.77679	.....	170.119	.....
			Mean, 170.109±.0030	97.717±.0022

From the Ag ratio = 207.181.

From the AgBr ratio Pb = 207.186.

And Ag : Br :: 100 : 74.075.

On account of the remarkable discovery, by several investigators, that the atomic weight of lead from radioactive minerals differs from that of ordinary or normal lead, it became desirable to determine whether the latter was constant, at least within the limits of experimental uncertainty. For this purpose Baxter and Grover [1] made elaborate series of analyses of lead bromide and chloride from very different sources. Lead was obtained from galena, cerussite, vanadinite, and wulfenite, and the minerals came from widely separated localities; namely, from Idaho, Arizona, Washington, Missouri, Germany, and Australia. Four different mineral species and seven localities furnished the material for the determinations. Commercial lead nitrate was also included in the investigation. First in order are the analyses of lead bromide, with corrected weights as usual.

$PbBr_2$.	*Ag.*	*AgBr.*	*Ag ratio.*	*AgBr ratio.*
5.27845	3.10271	.....	170.124	.....
2.65094	1.55822	.....	170.126	.....
4.08410	2.40104	.....	170.097	.....
4.97468	2.92473	.....	170.090	.....
4.05541	2.38398	4.15017	170.111	97.717
3.44139	2.02288	3.52224	170.123	97.705
5.17387	3.04158	5.29498	170.105	97.713
3.84497	2.26022	3.93446	170.115	97.726
4.30513	2.53086	4.40616	170.105	97.707
4.53445	2.66549	4.64048	170.117	97.715
5.78437	3.40044	5.91976	170.107	97.713
4.87079	2.86337	4.98467	170.107	97.715
6.28446	3.69447	6.43124	170.104	97.718
4.74639	2.79011	4.85708	170.115	97.721
6.82424	4.01148	6.98390	170.118	97.715
6.53689	3.84274	.....	170.110	.....
4.10098	2.41088	4.19791	170.103	97.691*
2.64256	1.55352	.....	170.101	.....
6.30683	3.70718	.....	170.125	.....
			Mean, 170.111±.0015.	97.715±.0013.

From the Ag ratio, Pb = 207.186.

From the AgBr ratio, Pb = 207.177.

And Ag : Br :: 100 : 74.089.

Combining the series of Baxter and Thorvaldson with that of Baxter and Grover the ratios become—

$2Ag : PbBr_2 :: 100 : 170.1106 \pm .0013$

$2AgBr : PbBr_2 :: 100 : 97.7154 \pm .0011$

[1] Journ. Amer. Chem. Soc., 37, 1027. 1915.

* Rejected by the authors. Not included in the mean.

Baxter and Grover also measured both chloride ratios, but separately. First, the ratio of lead chloride to silver chloride.

$PbCl_2$.	$AgCl$.	Ratio.
6.96370	7.17754	97.021
6.89046	7.10231	97.017
7.33227	7.55732	97.022
6.51699	6.71690	97.024
		Mean, 97.021±.0010

Hence, Pb = 207.221.

For the ratio between lead chloride and silver, Baxter and Grover give the following data:

$PbCl_2$.	Ag.	Ratio.
5.63527	4.37200	128.904
5.58730	4.33427	128.910
6.86319	5.32402	128.910
4.70770	3.65223	128.899
4.20222	3.25968	128.915
7.04688	5.46691	128.901
5.88935	4.56868	128.907
4.90083	3.80171	128.911
5.79300	4.49404	128.904
5.43965	4.21992	128.908
5.74504	4.45674	128.907
6.57216	5.09849	128.904
5.66330	4.39340	128.905
5.73434	4.44857	128.903
4.17445	3.23862	128.896
6.25884	4.85584	128.893
5.25882	4.07933	128.914
		Mean, 128.905±.0010

Hence, Pb = 207.205.

The values given here for the atomic weight of lead differ slightly from those found by Baxter and Grover because different values are assigned to chlorine and bromine.

Analyses of lead chloride have also been made by Hönigschmid and Horovitz,[1] whose data are as follows. The weights are corrected to a vacuum.

$PbCl_2$.	Ag.	AgCl.	Ag ratio.	AgCl ratio.
6.17861	4.79374	6.36895	128.889	97.011
4.75170	3.68659	4.89837	128.891	97.006
4.83377	3.75047	4.98528	128.890	97.004
			Mean, 128.890±.0004.	97.007±.0014.

From the Ag ratio, Pb = 207.172.

From the AgCl ratio, Pb = 207.180.

And Ag : Cl :: 100 : 32.867.

Four more determinations of the ratio of silver to lead chloride remain to be noticed; two by Richards and Wadsworth,[2] and two by Richards and Hall.[3] The values found are so close together that they may be taken here as one series. The figures are as follows:

$PbCl_2$.	Ag.	Ratio.	
3.72918	2.89325	128.892	R. and W.
5.35111	4.15151	128.896	
7.13723	5.53723	128.895	R. and H.
7.60063	5.89675	128.895	
		Mean, 128.894±.0005.	

Hence, Pb = 207.181.

The various determinations of the two lead chloride ratios can now be combined as follows:

[1] Monatsh. Chem., 36, 375. 1915. [2] Journ. Amer. Chem. Soc., 38, 2613. 1916. [3] Ibid., 39, 537. 1917.

First.

$2Ag : PbCl_2 :: 100 : x.$

Marignac with Dumas	128.727±.0130
Baxter and Wilson	128.849±.0010
Baxter and Grover	128.905±.0010
Hönigschmid and Horovitz	128.890±.0004
Richards, Wadsworth, and Hall	128.894±.0005
General mean	128.860±.00029

Second.

$2AgCl : PbCl_2 :: 100 : x.$

Marignac	96.890 ±.0704
Baxter and Wilson	96.978 ±.0039
Baxter and Grover	97.021 ±.0010
Hönigschmid and Horovitz	97.007 ±.0014
General mean	97.0147±.00081

Finally the ratio between lead nitrate and lead oxide, previously measured by Anderson, has been redetermined by Oechsner de Coninck and Gérard.[1] The nitrate was calcined to oxide, and both compounds were weighed. The data are as follows:

PbN_2O_6.	PbO.	Per cent PbO.
0.9054	0.6099	67.362
.7243	.4880	67.375
.8149	.5490	67.370
.6338	.4270	67.371
		Mean, 67.3695±.0023
		Anderson found, 67.4027±.0016
		General mean, 67.3922±.0013

From the new determination Pb = 207.01.

The following ratios are now available from which to compute the atomic weight of lead:

(1) $PbO : Pb :: 100 : 92.8271 \pm .0013$.
(2) $PbN_2O_6 : PbO :: 100 : 67.3922 \pm .0013$.
(3) $Pb : PbSO_4 :: 100 : 146.4262 \pm .0023$.
(4) $PbO : PbSO_4 :: 100 : 135.804 \pm .0180$.
(5) $Pb : PbN_2O_6 :: 100 : 159.9704 \pm .0010$.
(6) $Pb : PbCl_2 :: 100 : 134.191 \pm .0130$.
(7) $2Ag : PbCl_2 :: 100 : 128.860 \pm .00029$.
(8) $2AgCl : PbCl_2 :: 100 : 97.0147 \pm .00081$.
(9) $2Ag : PbBr_2 :: 100 : 170.1106 \pm .0013$.
(10) $2AgBr : PbBr_2 :: 100 : 97.7154 \pm .0011$.
(11) $2Ag : Pb :: 100 : 95.850 \pm .0019$.

Computing with—

Ag=107.880 ±.00016 Br=79.9228±.00015
Cl = 35.4605±.00011 S =32.0650±.00012
N=14.0081±.00008

we have—

From ratio—

5	Pb=206.796±.0035
11	206.806±.0042
3	206.920±.0102
1	207.062±.0376
6	207.107±.00069
10	207.179±.0042
9	207.185±.0028
8	207.202±.0024
2	207.243±.0099
6	207.426±.0787
4	207.623±.1124
General mean	Pb=207.102±.00062

[1] Compt. Rend., 163, 514. 1916.

This final result is probably, but not certainly, too low. The best modern determinations indicate that the atomic weight of lead is not far from 207.2. The lowering of the value, as given here, is partly due to the work of Stas on lead nitrate and lead sulphate and partly to that of Baxter and Wilson on lead chloride.

ADDENDUM.

Two recent determinations of the atomic weight of normal lead, by Davis,[1] were made in connection with a study of isotopic lead. Analyses of lead chloride gave the following figures:

$PbCl_2$.	*$AgCl$.*	*Ratio.*
0.94411	0.97264	97.067
1.24607	1.28454	97.005
		Mean, 97.036

Hence, Pb = 207.263.

These determinations are too discordant to be of much significance.

ISOTOPIC LEAD.

One of the most startling discoveries of modern chemistry has been the fact that the elements of highest atomic weight, namely, uranium and thorium, are unstable, and undergo a slow decomposition into simpler forms. Helium and radium are among the products of this disintegration, the process apparently ending with the production of lead. This lead differs appreciably in atomic weight from ordinary or normal lead, the atomic weight of the latter being nearly and perhaps absolutely constant. This constancy is clearly shown by the recent researches of Baxter and Grover, Hönigschmid and Horovitz, Richards and Lembert, Richards and Wadsworth, and Richards and Hall. The earlier discordances are due, partly to differences of method and technique, and partly to experimental errors.

Isotopic or radio-lead on the other hand, the lead derived from radioactive minerals, may be either higher or lower in atomic weight than normal lead, accordingly as it originates from thorium or uranium, and this fact has been determined by several competent investigators. Let us consider first the lead from uranium minerals.

In 1914 Maurice Curie [2] published the end results, without analytical details, of a series of atomic weight determinations of lead from different sources. The data are as follows:

Origin:	*At.wt.Pb.*
Pitchblende	206.64
Carnotite	206.36
Yttrotantalite	206.54
Monazite	207.08
Ordinary lead	207.01

These figures speak for themselves. The three leads from radioactive minerals have much lower atomic weights than the others.

At about the same time Richards and Lembert [3] published much more elaborate determinations than those of Curie. The material studied was derived from a variety of sources, and the lead, after careful purification, was converted into chloride, which was analyzed. The original minerals, which are indicated in the table of analyses by capital letters, were as follows:

D, P. Colorado carnotite.
H, M. Ceylonese thorianite.
I, K. Bohemian pitchblende.
G. English pitchblende.
R. North Carolina uraninite.

First come the determinations of the ratio $PbCl_2$: Ag, with vacuum weights, as follows:

Origin.	*$PbCl_2$.*	*Ag.*	*Ratio.*	*At. wt. Pb.*
D	3.87082	3.00984	128.606	206.56
D	5.57331	4.33300	128.625	206.60

[1] Journ. Phys. Chem., 22, 631. 1918. [2] Compt. Rend., 158, 1676, 1914. [3] Journ. Amer. Chem. Soc., 36, 1329. 1914.

Origin.	*$PbCl_2$.*	*Ag.*	*Ratio.*	*Al. wt. Pb.*
P	5. 49412	4. 27157	128. 621	206. 59
H	3. 88228	3. 01600	128. 723	206. 81
H	4. 05550	3. 15061	128. 722	206. 81
H	4. 05168	3. 14788	128. 712	206. 79
M	2. 80814	2. 18162	128. 718	206. 81
I	3. 95052	3. 07209	128. 594	206. 54
K	2. 95726	2. 29951	128. 604	206. 56
G	4. 05702	3. 15153	128. 732	206. 84
R	2. 01795	1. 56952	128. 563	206. 47

For the ratio $PbCl_2$: AgCl the following data are given:

Origin.	*$PbCl_2$.*	*AgCl.*	*Ratio.*	*At. wt. Pb.*
D	3. 87082	3. 99879	96. 799	206. 59
D	5. 57331	5. 75707	96. 808	206. 61
P	5. 49412	5. 67573	96. 800	206. 58
H	3. 88228	4. 00703	96. 886	206. 84
H	4. 05168	4. 18265	96. 870	206. 78
M	2. 80814	2. 89816	96. 894	206. 85
K	2. 95726	3. 05475	96. 809	206. 61
G	4. 05702	4. 18670	96. 903	206. 88
R	2. 01795	2. 08663	96. 767	206. 32

Two years later another series of determinations, by Richards and Wadsworth appeared.[1] The sources of the lead may be indicated by number, thus: 1. Australian carnotite. 2. Colorado carnotite. 3. Bröggerite, Norway. 4. Cleveite, Norway.

Origin.	*$PbCl_2$.*	*Ag.*	*Ratio.*	*At. wt. Pb.*
1	4. 64010	3. 61118	128. 493	206. 318
1	5. 35517	4. 16711	128. 512	206. 359
1	6. 15608	4. 79072	128. 500	206. 334
1	4. 14770	3. 22748	128. 512	206. 339
2	5. 31585	4. 12670	128. 816	207. 015
2	4. 65899	3. 61707	128. 806	206. 994
3	4. 29104	3. 34187	128. 402	206. 122
4	3. 92736	3. 05913	128. 382	206. 079
4	4. 45270	3. 46818	128. 387	206. 090

The determinations by Richards and Hall[2] were all made with lead from Australian carnotite. Their figures follow:

$PbCl_2$.	*Ag.*	*Ratio.*	*At. wt. Pb.*
3. 70016	2. 87854	128. 543	206. 426
4. 79633	3. 73154	128. 535	206. 409
4. 64577	3. 61412	128. 545	206. 431
4. 64736	3. 61568	128. 534	206. 406
4. 87838	3. 79579	128. 541	206. 422
4. 68396	3. 64425	128. 530	206. 399

The atomic weights were calculated with Ag = 107.88, and Cl = 35.459. With Cl = 35.4605 the atomic weight of lead would be 0.003 lower.

In 1914 several determinations of the atomic weight of lead from pitchblende were published by Hönigschmid,[3] whose data are as follows:

First series.

$PbCl_2$.	*AgCl.*	*Ratio.*	*At. wt. Pb.*
1. 97691	2. 04118	96. 851	206. 733
3. 04040	3. 13910	96. 856	206. 746
3. 05981	3. 15939	96. 848	206. 724
3. 30285	3. 41015	96. 854	206. 740
3. 33164	3. 44013	96. 857	206. 719
3. 22450	3. 32923	96. 857	206. 749

[1] Journ. Amer. Chem. Soc., 38, 2613. 1916. [2] Journ. Amer. Chem. Soc., 39, 531. 1917. [3] Zeitsch. Elektrochem., 20, 457. 1914.

Second series.

$PbCl_2$.	*Ag.*	*Ratio.*	*At. wt. Pb.*
3. 33164	2. 58888	128. 690	206. 748
3. 22459	2. 50586	128. 682	206. 730
3. 79447	2. 71545	128. 688	206. 744

In the following year this investigation was continued by Hönigschmid and Horovitz[1] with much greater elaboration. Lead was obtained from three different sources, namely, from the purest Joachimsthal pitchblende, from a crystallized uranium ore from Morogoro, German East Africa, and from Norwegian bröggerite. From this lead the chloride was prepared, and analyzed by the methods followed by Baxter and Wilson in their study of ordinary lead. The results obtained with vacuum weights from several series are as follows:

First.—Lead from pitchblende.

$PbCl_2$.	*AgCl.*	*Ratio.*	*At. wt. Pb.*
2. 91224	3. 01042	96. 739	206. 410
2. 47886	2. 56256	96. 734	206. 396
2. 76797	2. 86126	96. 740	206. 413

Second.—Ore from Morogoro, Ag series.

$PbCl_2$.	*Ag.*	*Ratio.*	*At. wt. Pb.*
3. 24177	2. 52563	128. 355	206. 024
3. 94867	3. 07636	128. 355	206. 025
3. 78263	2. 94693	128. 358	206. 033
3. 68899	2. 87400	128. 357	206. 030
4. 49731	3. 50343	128. 369	206. 054

Third.—From Morogoro, AgCl series.

$PbCl_2$.	*AgCl.*	*Ratio.*	*At. wt. Pb.*
3. 24177	3. 35537	96. 614	206. 054
3. 94867	4. 08686	96. 619	206. 066
3. 78263	3. 91519	96. 614	206. 053
3. 68899	3. 81830	96. 613	206. 052
4. 49731	4. 65464	96. 620	206. 070

Fourth.—From bröggerite, Ag series.

$PbCl_2$.	*Ag.*	*Ratio.*	*At.wt.Pb.*
4. 83605	3. 76724	128. 371	206. 060
3. 97826	3. 09903	128. 371	206. 060
4. 91204	3. 82647	128. 370	206. 057

Fifth.—From bröggerite, AgCl series.

$PbCl_2$.	*AgCl.*	*Ratio.*	*At.wt.Pb.*
4. 50069	4. 65794	96. 624	206. 082
4. 49363	4. 65060	96. 625	206. 084
4. 83605	5. 00512	96. 622	206. 076
3. 97826	4. 11741	96. 620	206. 072
4. 91204	5. 08425	96. 613	206. 050

In this series the first two analyses were only preliminary. The determinations of the atomic weight of normal lead by Hönigschmid and Horovitz have already been cited.

Two determinations of the atomic weight of isotopic lead from samarskite, by Davis,[2] are as follows:

$PbCl_2$.	*AgCl.*	*Ratio.*	*At.wt.Pb.*
1. 06795	1. 10199	96. 911	206. 905
. 73514	. 76011	96. 715	206. 342

[1] Monatsch. Chem., 36, 355. 1915.

[2] Journ. Phys. Chem., 22, 631. 1918.

Although these determinations do not agree, they confirm the lower atomic weight of isotopic lead as derived from another source.

Since the foregoing pages were put in type a short paper upon lead by Richards and Sameshima [1] has also appeared. The usual ratio of 2 Ag:$PbCl_2$ was determined for ordinary lead and also for lead from a radioactive Japanese mineral. The figures are as follows:

Ordinary lead.

Ag.	*$PbCl_2$.*	*Ratio.*	*At. wt. Pb.*
3.13929	2.43553	128.895	207.185
3.09476	2.40100	128.894	207.183
			Mean, 207.184

Japanese lead.

Ag.	*$PbCl_2$.*	*Ratio.*	*At. wt. Pb.*
2.16756	1.68212	128.859	207.11
1.14536	.88881	128.864	207.12
1.34496	1.04538	128.879	207.15
			Mean, 270.13

The Japanese material evidently contains very little isotopic lead.

The data relative to thorium lead are as yet not quite complete. Soddy and Hyman [2] examined lead derived from Ceylonese thorite, and found for its atomic weight the values 208.3, 208.4, and 208.5. This value is almost certainly excessive; for Hönigschmid [3] by analyses of lead chloride derived from Soddy's original material found Pb = 207.78. His data are as follows, with vacuum weights:

$PbCl_2$.	*AgCl.*	*At.wt.(Th)Pb.*
2.71471	2.79264	207.76
3.90048	4.01204	207.77
4.05682	4.17300	207.78
3.80951	3.91848	207.78
		Mean, 207.78

In another communication Soddy [4] from the specific gravity of thorium lead, assuming that normal and isotopic lead have identical molecular volumes, finds for the atomic weight of thorium lead the value 207.64. Still later Hönigschmid [5] found for the atomic weight of lead obtained from Norwegian thorite a much higher figure, namely, 207.90. Hönigschmid's original paper I have not seen. That thorium lead has a higher atomic weight than normal lead is, however, thoroughly established.

The time has not yet come for the final interpretation of these remarkable results, and yet they reveal some relations which are worth noting here. In the work of Richards and Lembert relatively high values were found for the atomic weight of lead from thorianite, a mineral which contains both uranium and thorium. This species therefore seems to contain both isotopes of lead, and possibly normal lead also. The lowest atomic weights are shown by the crystalline varieties of uraninite, namely, bröggerite, cleveite and the Morogoro mineral. Here, doubtless, we have the closest approach to the ideal uranium lead, which is supposed on theoretical grounds to have the atomic weight 206. In Hillebrand's [6] splendid series of analyses of uraninite and its varieties the highest proportion of helium was found in those which were most brilliantly crystalline. The massive varieties contained little or no helium, and the atomic weight of lead derived from them is now shown to be relatively high. There is, therefore, a clear relation indicated between the proportions of helium and isotopic lead in uraninite, which cannot be without significance. Moreover, as shown by Hillebrand's analyses, nearly all uraninites contain more or less thorium, which suggests that both isotopes are present in them, but with

[1] Journ. Amer. Chem. Soc., 42, 929. May, 1920.
[2] Journ. Chem. Soc., 105, 1402. 1914.
[3] Zeitschr. Elektrochem., 23, 161. 1917.
[4] Nature, 94, 615, 1915.
[5] Cited by Fajans, Zeitschr. Elektrochem., 26, 163. 1918.
[6] Amer. Journ. Sci., 40, 384. 1890.

uranium lead predominating. A comparison of the atomic weights given in the preceding pages with the analyses of the minerals from which they were derived would surely be interesting. It would also be worth while to determine the atomic weight of lead obtained from minerals associated with uraninite, but not contained in it. It seems probable that all uraninites and thorites contain more or less normal lead which was inclosed or dissolved in them at the time of their formation; the two isotopes having been developed later.

It has been suggested by some writers that normal lead is a mixture in equal or nearly equal proportions of the two isotopes; but on that basis it is difficult to account for the constancy of atomic weight of the ordinary metal. One or the other of the isotopes would be likely to predominate. I now venture to offer a different interpretation of the evidence, which may seem to be extravagant, but which is at least worth considering. Normal lead may be regarded as having been generated in the orderly evolution of the chemical elements, an evolution which is indicated by the progressive complexity of the spectra of the heavenly bodies, as I pointed out many years ago.[1] Isotopic lead, on the other hand, is a product of degradation, and might be looked upon as in a sense defective lead—lead which has lost or gained something from its normal constitution. The atoms of the elements are now known to be complex, with nuclei surrounded by electrons. If we suppose the three forms of lead to have identical nuclei, to which their most characteristic properties are due, we can imagine that slight changes in mass and density are ascribable to corresponding changes in their envelopes. That this is pure speculation must be admitted, but it may help to suggest future lines of research.

GLUCINUM.

Our knowledge of the atomic weight of glucinum is derived from experiments made upon the sulphate and two salts. Leaving out of account the determinations by Berzelius,[2] Awdejew,[3] Weeren,[4] Klatzo,[5] and Debray,[6] we have to consider only three modern investigations, for the older work is no longer of real value. It is cited in detail in the former editions of this recalculation.

In 1880 the careful determinations of Nilson and Pettersson appeared.[7] These chemists first attempted to work with the sublimed chloride of glucinum, but abandoned the method upon finding the compound to be contaminated with traces of lime derived from a glass tube. They finally resorted to the crystallized sulphate as the most available salt for their purposes. This compound, upon strong ignition, yields pure glucina. The data are as follows:

$GlSO_4.4H_2O$.	GlO.	Per cent GlO.
3.8014	0.5387	14.171
2.6092	.3697	14.169
4.3072	.6099	14.160
3.0091	.4266	14.176
		Mean, 14.169±.0023

Hence, Gl = 9.113.

Krüss and Moraht [8] in their work followed the general method adopted by Nilson and Pettersson, but with various added precautions and greater elaboration of detail. Their glucina was derived from three sources, namely, leucophane, beryl, and gadolinite, and the sulphate was repeatedly recrystallized. The results are as follows:

$GlSO.4H_2O$.	GlO.	Per cent GlO.
21.1928	3.0008	14.160
16.2038	2.29455	14.161
15.49345	2.1902	14.136
20.1036	2.8433	14.143
22.0465	3.1167	14.137
4.9619	.7019	14.146
18.3249	2.5921	14.145

[1] Popular Science Monthly, January, 1873.
[2] Poggend. Annal., 8, 1.
[3] Poggend. Annal., 56, 106. 1842.
[4] Poggend. Annal., 92, 124. 1854.
[5] Zeitsch. anal. Chem., 8, 533. 1869.
[6] Ann. Chim. Phys., (3), 44, 37. 1855.
[7] Ber. Deutsch. chem. Ges., 13, 1451. 1880.
[8] Liebig's Annalen, 262, 38. 1891.

$GlSO.4H_2O$.	GlO.	Per cent GlO.
24. 3907	3. 0253	14. 143
20. 18045	2. 85255	14. 135
20. 0253	2. 8328	14. 146
18. 9840	2. 6832	14. 134
17. 0072	2. 4073	14. 155
22. 5044	3. 1805	14. 133
20. 88675	2. 95645	14. 154
19. 0591	2. 69305	14. 130
17. 8227	2. 5226	14. 153
		Mean, 14. 144±. 0017

Hence, Gl = 9.065.

The first two determinations, which give the highest percentage, were made upon sulphate thrice crystallized. The others were made upon a salt four times crystallized, except in one instance, when there were five crystallizations. To the data derived from the four times crystallized compound Krüss and Moraht give preferance, and so find a slightly lower value for the atomic weight of glucinum. Combining, we have for the mean percentage:

By Nilson and Pettersson	14. 169±. 0023
By Krüss and Moraht	14. 144±. 0017
General mean	14. 153±. 0014

The determinations, by Parsons,[1] of this atomic weight, were based upon analyses of two organic salts, namely, the acetylacetonate, $Gl(C_5H_7O_2)_2$, and the basic acetate, $Gl_4O(C_2H_3O_2)_6$. These compounds are volatile at moderately high temperatures, and can therefore be purified by sublimation; an advantage which the sulphate does not possess. Parsons attempted to make determinations with sulphate, also but obtained unsatisfactory results.

Weighed quantities of the two organic compounds were first decomposed, in platinum crucibles, with nitric acid. The nitrate solutions so formed were then evaporated to dryness, and the residual salt was converted into oxide by prolonged ignition. The oxide was examined for occluded gases, and its weight was given the necessary correction for them. The data obtained, with vacuum weights, were as follows:

Acetylacetonate.	*Oxide.*	*Per cent GlO.*
2. 62245	0. 31798	12. 125
3. 28037	. 39757	12. 119
2. 08993	. 25286	12. 099
2. 41401	. 29233	12. 109
1. 61353	. 19554	12. 118
1. 39714	. 16905	12. 100
1. 85023	. 22419	12. 117
		Mean, 12. 1124±. 0025

Hence, Gl = 9.101.

Acetate.	*Oxide.*	*Per cent GlO.*
2. 61484	0. 64630	24. 716
2. 67721	. 66109	24. 693
3. 11534	. 76930	24. 693
1. 89291	. 46788	24. 717
1. 47931	. 36534	24. 703
1. 09012	. 26911	24. 686
1. 35642	. 33493	24. 692
1. 56787	. 38715	24. 693
1. 34465	. 33204	24. 693
		Mean, 24. 698±. 0025

Hence, Gl = 9.1046.

In a later note,[2] Parsons combined the two series of determinations, and deduced simultaneous values for Gl and C. If O = 16, and H = 1.008, then Gl = 9.112, and C = 12.007. These figures furnish a good check upon the general accuracy of the manipulations.

[1] Journ. Amer. Chem. Soc., 26, 721. 1904.

[2] Journ. Amer. Chem. Soc., 27, 1204. 1905.

The atomic weight of glucinum is now fixed by the following ratios:

(1) $GlSO_4.4H_2O : GlO :: 100 : 14.153 \pm .0014$
(2) $Gl(C_5H_7O_2)_2 : GlO :: 100 : 12.1124 \pm .0025$
(3) $Gl_4O(C_2H_3O_2)_6 : 4GlO :: 100 : 24.698 \pm .0025$

Reducing these ratios with

$C = 12.0025 \pm .00019$
$S = 32.0650 \pm .00012$
$H = 1.0078 \pm .00001$

we have—

From ratio 1	Gl=9.0802±.0026
2	9.1012±.0052
3	9.1046±.0026
General mean	Gl=9.0934±.0017

For all practical purposes the atomic weight of glucinum may be taken as 9.1, which must be very near the true value.

MAGNESIUM.

There is perhaps no common metal of which the atomic weight has been subjected to closer scrutiny than that of magnesium. The value is low, and its determination should, therefore, be relatively free from many of the ordinary sources of error; it is extensively applied in chemical analysis, and ought consequently to be accurately ascertained.

The early determinations made by Berzelius, Longchamp and Gay-Lussac need not be considered here, as they have only antiquarian value. The investigations which demand attention are those of Scheerer, Svanberg and Nordenfeldt, Jacquelain, Macdonnell, Bahr, Marchand and Scheerer, Dumas, Marignac, Burton and Vorce, and Richards and Parker.

Scheerer's method of investigation was exceedingly simple.[1] He merely estimated the sulphuric acid in anhydrous magnesium sulphate, employing the usual process of precipitation as barium sulphate. He gives no weighings, but reports the percentages of SO_3 thus found. In his calculations, $O = 100$, $SO_3 = 500.75$, and $BaO = 955.29$. It is easy, therefore, to recalculate the figures which he gives, so as to establish what his method really represents, namely, the ratio between the sulphates of barium and magnesium.

Thus revised, his four analyses show that 100 parts of $MgSO_4$ yield the following quantities of $BaSO_4$:

$BaSO_4$.	*Per cent SO_3.*
193.575	66.573
193.677	66.608
193.767	66.639
193.631	66.592
Mean, 193.6625±.0274	

Hence, Mg = 24.466.

In a later note[2] Scheerer shows that the barium sulphate of these experiments carries down with it magnesium salts in such quantity as to make the atomic weight of magnesium 0.039 too low.

The work of Bahr, Jacquelain, Macdonnell, and Marignac, and in part that of Svanberg and Nordenfeldt, also relates to the composition of magnesium sulphate.

Jacquelain's experiments were as follows:[3] Dry magnesium sulphate was prepared by mixing the ordinary hydrous salt to a paste with sulphuric acid, and calcining the mass in a platinum crucible over a spirit lamp to constant weight and complete neutrality of reaction. This dry sulphate was weighed and intensely ignited three successive times. The weight of the residual MgO having been determined, it was moistened with sulphuric acid and recalcined over a spirit lamp, thus reproducing the original weight of $MgSO_4$. Jacquelain's weighings for these

[1] Poggend. Annal., 69, 535. 1846. [2] Poggend. Annal., 70, 407. [3] Ann. Chim. Phys. (3), 32, 202.

two experiments show that 100 parts of MgO correspond to the quantities of $MgSO_4$ given in the last column:

1.466 grm. $MgSO_4$ gave	.492 grm. MgO.	297.968
.492 grm. MgO gave	1.466 grm. $MgSO_4$.	297.968

Hence, Mg = 24.443.

Jacquelain also made one estimation of sulphuric acid in the foregoing sulphate as $BaSO_4$. His result (1.464 grm. $MgSO_4$ = 2.838 grm. $BaSO_4$), reduced to the standard adopted in dealing with Scheerer's experiments, gives for 100 parts of $MgSO_4$, 193.852 $BaSO_4$. If this figure be given equal weight with a single experiment in Scheerer's series, and combined with the latter, the mean will be 193.700 ± .0331. This again is subject to the correction pointed out by Scheerer for magnesium salts retained by the barium sulphate, but such a correction determined by Scheerer for a single experiment is only a rough approximation, and hardly worth applying.

The determinations published by Macdonnell [1] are of slight importance, and all depend upon magnesium sulphate. First, the crystallized salt, $MgSO_4.7H_2O$, was dried in vacuo over sulphuric acid and then dehydrated at a low red heat. The following percentages of water were found:

51.17	51.26
51.13	51.28
51.14	51.29

Mean, 51.21 ± .020

Secondly, anhydrous magnesium sulphate was precipitated with barium chloride. From the weight of the barium sulphate, with SO_3 = 80 and Ba = 137, Macdonnell computes the percentages of SO_3 given below. I calculate them back to the observed ratio in uniformity with Scheerer's work:

Per cent. SO_3.	*Ratio, $MgSO_4$: $BaSO_4$.*
66.67	194.177
66.73	194.351
66.64	194.089
66.65	194.118
66.69	194.239

In another experiment 60.05 grains $MgSO_4$ gave 116.65 grains $BaSO_4$, a ratio of 100 : 194.254. Including this with the preceding figures, they give a mean of 194.205 ± .027. This, combined with the work of Scheerer and Jacquelain, 193.700 ± .033, gives a general mean of—

$$MgSO_4 : BaSO_4 :: 100 : 194.003 \pm .021$$

In one final experiment Macdonnell found that 41.44 grains of pure magnesia gave 124.40 grains of $MgSO_4$, or 300.193 per cent.

From Macdonnell's data the atomic weight of magnesium ranges between 24.00 and 24.43.

Bahr's [2] work resembles in part that of Jacquelain. This chemist converted pure magnesium oxide into sulphate, and from the increase in weight determined the composition of the latter salt. From his weighings 100 parts of MgO equal the amounts of $MgSO_4$ given in the third column:

MgO.	*$MgSO_4$.*	*Ratio.*
1.6938	5.0157	296.122
2.0459	6.0648	296.437
1.0784	3.1925	296.040

Mean, 296.200 ± .0815

Hence, Mg = 24.807.

About four years previous to the investigations of Bahr the paper of Svanberg and Nordenfeldt [3] appeared. These chemists started with the oxalate of magnesium, which was dried at a temperature of from 100° to 105° until it no longer lost weight. The salt then contained two molecules of water, and upon strong ignition it left a residue of MgO. The percentage of MgO in the oxalate was as follows.

[1] Proc. Royal Irish Acad., 5, 303. British Assoc. Report, 1852, part 2, p. 36.
[2] Journ. prakt. Chem., 56, 310. 1852.
[3] Journ. prakt. Chem., 45, 473. 1848.

Oxalate.	*MgO.*	*Per cent.*
7.2634	1.9872	27.359
6.3795	1.7464	27.375
6.3653	1.7418	27.364
6.2216	1.7027	27.368
		Mean, 27.3665±.0023

Hence, Mg = 24.704.

In three of these experiments the MgO was treated with H_2SO_4 and converted, as by Jacquelain and by Bahr in their later researches, into $MgSO_4$. One hundred parts of MgO gave of $MgSO_4$ as follows:

MgO.	*$MgSO_4$.*	*Ratio.*
1.9872	5.8995	296.875
1.7464	5.1783	296.513
1.7418	5.1666	296.624
		Mean, 296.671±0.072

Hence, Mg = 24.710.

In 1850 the elaborate investigations by Marchand and Scheerer [1] appeared. These chemists undertook to determine the composition of some natural magnesites, and, by applying corrections for impurities, to deduce from their results the sought-for atomic weight. The magnesite chosen for the investigation was, first, a yellow, transparent variety from Snarum; second, a white opaque mineral from the same locality; and, third, a very pure quality from Frankenstein. In each case the impurities were carefully determined, but only a part of the details need be cited here. Silica was, of course, easily corrected for by simple subtraction from the sum of all of the constituents; but iron and calcium, when found, having been present in the mineral as carbonates, required the assignment to them of a portion of the carbonic acid. In the atomic weight determinations the mineral was first dried at 300°. The loss in weight upon ignition was then carbon dioxide. It was found, however, that even here a correction was necessary. Magnesite, upon drying at 300°, loses a trace of CO_2 and still retains a little water; on the other hand, a minute quantity of CO_2 remains even after ignition. The CO_2 expelled at 300° amounted in one experiment to 0.054 per cent; that retained after calcination to 0.055 per cent. Both errors tend in the same direction and increase the apparent percentage of MgO in the magnesite. On the yellow mineral from Snarum the crude results are as follows giving percentages of MgO, FeO, and CO_2 after eliminating silica:

CO_2	*MgO.*	*FeO.*
51.8958	47.3278	0.7764
51.8798	47.3393	.7809
51.8734	47.3154	.8112
51.8875	47.3372	.7753
	Mean, 47.3299±0.0037.	

After applying corrections for loss and retention of CO_2, as previously indicated, the mean results of the foregoing series become—

CO_2	*MgO.*	*FeO.*
51.9931	47.2743	.7860

The ratio between the MgO and the CO_2, after correcting for the iron, will be considered further on.

Of the white magnesite from Snarum but a single analysis was made, which for present purposes may be ignored. As for the Frankenstein mineral three series of analyses were executed. In the first series the following results were obtained:

CO_2	*MgO.*	*Per cent.*
8.996	8.2245	47.760
7.960	7.2775	47.761
9.3265	8.529	47.767
7.553	6.9095	47.775
		Mean, 47.766±.0022

[1] Journ. prakt. Chem., 50, 385.

This mean, corrected for loss of CO_2 in drying, becomes 47.681. I give series second with corrections applied:

$MgCO_3$	MgO.	*Per cent.*
6.8195	3.2500	47.658
11.3061	5.3849	47.628
9.7375	4.635	47.599
12.3887	5.9033	47.650
32.4148	15.453	47.674
38.8912	18.5366	47.663
26.5223	12.6445	47.675
		Mean, 47.650±.0069

The third series was made upon very pure material, so that the corrections, although applied, were less influential. The results were as follows:

$MgCO_3$	MgO.	*Per cent.*
4.2913	2.0436	47.622
27.8286	13.2539	47.627
14.6192	6.9692	47.672
18.3085	8.7237	47.648
		Mean, 47.642±.0077

In a supplementary paper[1] by Scheerer, it was shown that an important correction to the foregoing data had been overlooked. Scheerer, reexamining the magnesites in question, discovered in them traces of lime, which had escaped notice in the original anlayses. With this correction the two magnesites in question exhibit the following mean composition:

	Snarum.	*Frankenstein.*
CO_2	52.131	52.338
MgO	46.663	47.437
CaO	.430	.225
FeO	.776	.....
	100.000	100.000

Correcting for lime and iron, by assigning each its share of CO_2, the Snarum magnesite gives as the true percentage of magnesia in pure magnesium carbonate, the figure 47.624. To this, without serious mistake, we may assign the weight indicated by the probable error, ±.0037, the quantity previously deduced from the percentages of MgO given in the uncorrected analyses.

From the Frankenstein mineral, similarly corrected, the final mean percentage of MgO in $MgCO_3$ becomes 47.628. This, however, represents three series of analyses, whose combined probable errors may be properly assigned to it. The combination is as follows:

±.0022
±.0069
±.0077

Result, ±.0020, probable error of the general mean.

We may now combine the results obtained from both magnesites:

Snarum mineral	Per cent MgO, 47.624±.0037
Frankenstein mineral	" 47.628±.0020
General mean	Per cent MgO, 47.627±.0018

Hence Mg = 24.015.

The next investigation upon the atomic weight of magnesium which we have to consider is that of Dumas.[2] Pure magnesium chloride was placed in a boat of platinum, and ignited in a stream of dry hydrochloric acid gas. The excess of the latter having been expelled by a current of dry carbon dioxide, the platinum boat, still warm, was placed in a closed vessel and weighed therein. After weighing, the chloride was dissolved and titrated in the usual manner with a solution containing a known quantity of pure silver. The weighings which

[1] Ann. Chem. Pharm., 110, 240.

[2] Ann. Chem. Pharm., 113, 33. 1860.

Dumas reports give, as proportional to 100 parts of silver, the quantities of $MgCl_2$ stated in the third column:

$MgCl_2$	*Ag.*	*Ratio.*
2. 203	4. 964	44. 380
2. 5215	5. 678	44. 408
2. 363	5. 325	44. 376
3. 994	9. 012	44. 319
2. 578	5. 834	44. 189
2. 872	6. 502	44. 171
2. 080	4. 710	44. 161
2. 214	5. 002	44. 262
2. 086	4. 722	44. 176
1. 688	3. 823	44. 154
1. 342	3. 031	44. 276
		Mean, 44. 261 ± . 020

Hence, Mg = 24.77.

This determination gives a very high value to the atomic weight of magnesium, which is unquestionably wrong. The error, probably, is due to the presence of oxychloride in the magnesium chloride taken, an impurity tending to raise the apparent atomic weight of the metal. Richards' and Parker's revision of this ratio is more satisfactory.

Marignac,[1] in 1883, resorted to the old method of determination, depending upon the direct ratio between MgO and SO_3. This ratio he measured both synthetically and analytically. First, magnesia from various sources was converted into sulphate. The $MgSO_4$ from 100 parts of MgO is given in the third column:

	MgO.	*MgSO.*	*Ratio.*
1	1. 5635	4. 6620	298. 17
2	1. 4087	4. 2025	298. 32
3	1. 5917	4. 7480	298. 30
4	1. 4705	4. 3855	298. 23
5	1. 4778	4. 4060	298. 15
6	1. 6267	4. 8530	298. 33
7	1. 3657	4. 0740	298. 37
8	1 9575	5. 8390	298. 29
9	1. 6965	5. 0600	298. 26
10	1. 8680	5. 5715	298. 26
			Mean, 298. 27 ± . 0149

Hence, Mg = 24.382.

The magnesia for experiments 1 to 5 was prepared by calcination of the nitrate, that of 6 to 8 from the sulphate, and the remaining two from the carbonate. But Richards and Rogers[2] have shown that magnesia derived from the nitrate always contains occluded gaseous impurity, so that the experiments depending upon its use are somewhat questionable. The results tend to give an atomic weight for magnesium which is possibly too high. Whether the other samples of magnesia are subject to similar objections I can not say.

Marignac's second series was obtained by the calcination of the sulphate, with results as follows:

MgSO.	*MgO.*	*Ratio.*
3. 7705	1. 2642	298. 25
4. 7396	1. 5884	298. 39
3. 3830	1. 1345	298. 19
4. 7154	1. 5806	298. 33
4. 5662	1. 5302	298. 43
4. 5640	1. 5300	298. 30
3. 2733	1. 0979	298. 14
4. 8856	1. 6378	298. 30
5. 0092	1. 6792	298. 31
5. 3396	1. 7898	298. 33
5. 1775	1. 7352	298. 38
5. 0126	1. 6807	298. 24
5. 0398	1. 6894	298. 32
		Mean, 298. 30 ± . 0150

Hence, Mg = 24.376.

[1] Arch. Sci. Phys. Nat. (3), 10, 206. Oeuvres Complètes, 2, 742.

[2] Amer. Chem. Journ., 15, 567. 1893.

These data may now be combined with the work of previous investigators, giving Macdonnell's one result and Jacquelain's two, each equal weight with a single experiment in Bahr's series:

Macdonnell	300.193±.1413
Jacquelain	297.968±.0999
Bahr	296.200±.0815
Svanberg and Nordenfeldt	296.671±.0720
Marignac, synthetic	298.27 ±.0149
Marignac, calcination	298.30 ±.0150
General mean	298.210±.0103

Burton and Vorce,[1] who published their work on magnesium in 1890, began with the metal itself, which had been purified by distillation in a Sprengel vacuum. This metal was dissolved in pure nitric acid, and the resulting nitrate was converted into oxide by calcination at a white heat. The oxide was carefully tested for oxides of nitrogen, which were proved to be absent, but occluded gases, the impurity pointed out by Richards and Rogers, were not suspected. This impurity must have been present, and it would tend to lower the apparent atomic weight of magnesium as calculated from the data obtained. The results were as follows, together with the percentage of Mg in MgO:

Mg taken.	*MgO formed.*	*Per cent Mg.*
0.33009	0.54766	60.273
.34512	.57252	60.281
.26058	.43221	60.290
.28600	.47432	60.297
.30917	.51273	60.299
.27636	.45853	60.271
.36457	.60475	60.284
.32411	.53746	60.304
.32108	.53263	60.282
.28323	.46988	60.262
	Mean,	60.2845±.0027

Hence, Mg = 24.287.

The best determinations of all are those of Richards and Parker,[2] who studied magnesium chloride with all the precautions suggested by the most recent reaches. The salt itself was not only free from oxychloride, but also spectroscopically pure as regards alkaline contaminations, and all weighings were reduced to a vacuum. The first series of experiments gives the ratio between silver chloride and magnesium chloride, and I have reduced the data to the form $2AgCl : MgCl_2 :: 100 : x$. The weighings and values for x are subjoined:

$MgCl_2$.	*AgCl.*	*Ratio.*
1.33550	4.01952	33.225
1.51601	4.56369	33.219
1.32413	3.98528	33.226
1.40664	4.23297	33.231
1.25487	3.77670	33.227
	Mean,	33.226±.0013

Hence, Mg = 24.332.

The remaining series of experiments, three in number, relate to the ratio $2Ag : MgCl_2$, which was earlier investigated by Dumas. For the elaborate details of manipulation the original memoir must be consulted. I can give little more than the weights found, and their reduction to the usual form of ratio, $2Ag : MgCl_2 :: 100 : x$:

Second Series.

$MgCl_2$.	*Ag.*	*Ratio.*
2.78284	6.30284	44.152
2.29360	5.19560	44.145
2.36579	5.35989	44.130
	Mean,	44.142±.0043

Hence, Mg = 24.320.

[1] Amer. Chem. Journ., 12, 219. 1890.

[2] Zeitsch. anorg. Chem., 13, 81. 1896.

This series gives slightly higher results than the others, and the authors, for reasons which they assign, discard it:

Third Series.

$MgCl_2$.	*Ag.*	*Ratio.*
1.99276	4.51554	44.131
1.78870	4.05256	44.138
2.12832	4.82174	44.140
2.51483	5.69714	44.141
2.40672	5.45294	44.136
1.95005	4.41747	44.144
		Mean, 44.138±.0013

Hence, Mg=24.311.

The fourth series, because of the experience gained in the conduct of the preceding determinations, is best of all, and the authors adopt its results in preference to the others:

Fourth Series.

$MgCl_2$.	*Ag.*	*Ratio.*
2.03402	4.60855	44.136
1.91048	4.32841	44.138
2.09932	4.75635	44.137
1.82041	4.12447	44.137
1.92065	4.35151	44.138
1.11172	2.51876	44.138
		Mean, 44.137±.0003

Hence, Mg=24.311.

These series combine with that of Dumas as follows:

Dumas	44.261±.0200
Richards and Parker, second series	44.142±.0043
Richards and Parker, third series	44.138±.0013
Richards and Parker, fourth series	44.137±.0003
General mean	44.138±.0003

Here the first two values practically vanish, and the third and fourth series of Richards and Parker appear alone. Combining this figure with their value for the AgCl ratio, the subjoined cross ratio appears: Ag:Cl: :100: 32.842.

To sum up, we now have the following ratios, bearing upon the atomic weight of magnesium:

(1) $MgSO_4$: $BaSO_4$: :100: 194.003 ±.021
(2) MgO: $MgSO_4$: :100: 298.210 ±.0103
(3) Per cent of water in $MgSO_4$, $7H_2O$, 51.21 ±.020
(4) Per cent of MgO in oxalate, 27.3665 ±.0023
(5) Per cent of MgO in carbonate, 47.627 ±.0018
(6) Per cent of Mg in MgO, 60.2845 ±.0027
(7) 2Ag: $MgCl_2$: :100: 44.138 ±.0003
(8) 2AgCl: $MgCl_2$: :100: 33.226 ±.0013

The antecedent vales for reducing these ratios are—

Ag=107.880 ±.00016	S=32.065 ±.00012
Cl=35.4605±.00011	C=12.0025±.00019
Ba=137.358 ±.0023	H=1.0078±.00001

Hence,

From ratio—	
5	Mg=24.015±.0021
3	24.085±.0680
1	24.254±.0131
6	24.287±.0020
7	24.311±.0007
8	24.332±.0037
2	24.394±.0021
4	24.703±.0053
General mean	Mg=24.296±.0006

This final value is possibly a little too low, as compared with the individual values which are presumably the best. The figures are, however, peculiarly instructive. Ratios 2, 7, and 8, representing essentially the work of Marignac and Richards and Parker, were originally reduced with the Stas values for sulphur, silver and chlorine. These values are Ag = 107.93 Cl = 35.457 and S = 32.074. With these figures, and using only Marignac's data for ratio 2, the following values for magnesium are obtained:

From $MgSO_4$: MgO, Mg = 24.383
From 2Ag : $MgCl_2$, Mg = 24.382
From 2AgCl : $MgCl_2$, Mg = 24.371

From the general mean represented by ratio 2, Mg = 24.398, a slightly higher value.

The concordance here is much greater than in the reduction with modern values, and may be interpreted in either of two ways. Either the Stas values are more exact than the new values for Ag, Cl and S, or the earlier concordance is deceptive. In short, an agreement between determinations of atomic weight made by diverse methods, is dependent in great part upon the antecedent values used in the computations. Concordance and discordance may be equally deceptive. Illustrations of this statement are not uncommon.

ZINC.

The several determinations of the atomic weight of zinc are by no means closely concordant. The results obtained by Gay-Lussac [1] and Berzelius [2] were undoubtedly too low, and may be disregarded here. We need consider only the work done by later investigators.

In 1842 Jacquelain published the results of his investigations upon this important constant.[3] In two experiments a weighed quantity of zinc was converted into nitrate, and that by ignition in a *platinum* crucible was reduced to oxide. In two other experiments sulphuric acid took the place of nitric. As the zinc contained small quantities of lead and iron, these were estimated, and the necessary corrections applied. From the weights of metal and oxide given by Jacquelain the percentages have been calculated:

Nitric Series.

Zn.	*ZnO.*	*Per cent Zn.*
9.917	12.3138	80.536
9.809	12.1800	80.534

Sulphuric Series.

Zn.	*ZnO.*	*Per cent Zn.*
2.398	2.978	80.524
3.197	3.968	80.570

Mean of all four, 80.541 ± .007

Hence, Zn = 66.224.

The method adopted by Axel Erdmann[4] is essentially the same as that of Jacquelain, but varies from the latter in certain important details. First, pure zinc oxide was prepared, ignited in a covered crucible with sugar, and then, to complete the reduction, ignited in a porcelain tube in a current of hydrogen. The pure zinc thus obtained was converted into oxide by means of treatment with nitric acid and subsequent ignition in a *porcelain* crucible. Erdmann's figures give us the following percentages of metal in the oxide:

80.247 80.263
80.257 80.274

Mean, 80.260 ± .0037

Hence, Zn = 65.054.

Upon comparing Erdmann's results with those of Jacquelain two points are worth noticing: First, Erdmann worked with purer material than Jacquelain, although the latter applied corrections for the impurities which he knew were present; secondly, Erdmann calcined his

[1] Mémoire d'Arceuil, 2, 174.
[2] Gilb. Annal., 37, 460.
[3] Compt. Rend., 14, 636.
[4] Poggend. Annal., 62, 611. Berz. Lehrb., 3, 1219.

zinc nitrate in a porcelain crucible, while Jacquelain used platinum. In the latter case it has been shown that portions of zinc may become reduced and alloy themselves with the platinum of the crucible; hence a lower weight of oxide from a given quantity of zinc, a higher percentage of metal, and an increased atomic weight. This source of constant error has undoubtedly affected Jacquelain's experiments, and vitiated his results. In Erdmann's work no such errors seem to be present.

Favre[1] employed two methods of investigation. First, zinc was dissolved in sulphuric acid, the hydrogen evolved was burned, and the weight of water thus formed was determined. To his weighings I append the ratio between metallic zinc and 100 parts of water:

Zn.	*H_2O.*	*Ratio.*
25. 389	6. 928	366. 469
30. 369	8. 297	366. 024
31. 776	8. 671	366. 463
		Mean, 366. 319 ± . 088

Hence Zn = 65.995.

The second method adopted by Favre was to burn pure zinc oxalate, and to weigh the oxide and carbonic acid thus produced. From the ratio between these two sets of weights the atomic weight of zinc is easily deducible. From Favre's weighings, if $CO_2 = 100$, ZnO will be as given in the third column below:

ZnO.	*CO_2*	*Ratio.*
7. 796	8. 365	93. 198
7. 342	7. 883	93. 137
5. 2065	5. 588	93. 173
		Mean, 93. 169 ± . 012

Hence Zn = 65.993.

Both of these determinations are open to objections. In the water series it was essential that the hydrogen should first be throughly dried before combustion, and then that every trace of water formed should be collected. A trivial loss of hydrogen or of water would tend to increase the apparent atomic weight of zinc.

In the combustion of the zinc oxalate equally great difficulties are encountered. Here a variety of errors are possible, such as are due, for example, to impurity of material, to imperfect drying of the carbon dioxide, and to incomplete collection of the latter. Indeed, a fourth combustion is omitted from the series as given, having been rejected by Favre himself. In this case the oxide formed was contaminated by traces of sulphide.

Baubigny,[2] in 1883, resorted to the well-known sulphate method. Zinc sulphate, elaborately purified, was dried at 440° to constant weight, and then calcined at a temperature equal to the fusing point of gold. These data were obtained:

$ZnSO_4$	*ZnO.*	*Per cent ZnO.*
6. 699	3. 377	50. 410
8. 776	4. 4245	50. 416
		Mean, 50. 413 ± . 0020

Hence Zn = 65.399.

In Marignac's determinations of the atomic weight of zinc, published also in 1883,[3] there is a peculiar complication. After testing and criticizing some other methods, he finally decided to study the double salt K_2ZnCl_4, which, however, is difficult to obtain in absolutely definite condition. Although the compound was purified by repeated crystallizations, it was found to deliquesce readily, and thereby to undergo partial dissociation, losing chloride of zinc, and leaving the porous layer on the crystalline surfaces richer in potassium. In order to evade this difficulty, Marignac placed a large quantity of the salt in a funnel, and collected the liquid product of deliquescence as it ran down. In this product he determined chlorine by volumetric titration with a standard solution of silver, and also estimated zinc by precipitation with sodium

[1] Ann. Chim. Phys. (3), 10, 163. 1844.
[2] Compt. Rend., 97, 906. 1883.
[3] Arch. Sci. Phys. Nat. (3), 10, 194. Oeuvres Complètes, 2, 731.

carbonate, and weighing as oxide. From the data thus obtained equations were formed, giving for each analysis an atomic weight of zinc which is independent of the proportion between $ZnCl_2$ and KCl in the substance analyzed. The data unfortunately are too bulky for reproduction here and the calculations are complex; but the results found for zinc, when Ag = 107.93, Cl = 35.457, and K = 39.137, are as follows:

1. One titration	Zn = 65.22
2. Two titrations	65.37
3. Two titrations	65.31
4. Two titrations	65.28
5. One titration	65.26

Each of these values represents a distinct sample of the deliquesced material, and the number of chlorine determinations is indicated.

A second set of determinations was made by the same analytical method directly upon the recrystallized and carefully dried K_2ZnCl_4. The values for Zn are as follows:

6. Two titrations	Zn = 65.28
7. Two titrations	65.39
8. One titration	65.32

In order to adapt these data to the uniform scheme of calculation employed in this work, taking into account their probable error and the probable errors of the antecedent values for K, Cl and Ag, it seems to be best to calculate them back with the atomic weights used by Merignac into the form of the ratio $4Ag : K_2ZnCl_4 :: 100 : x$. Doing this, and taking each value as many times as there are titrations represented in it—that is, giving the results of a double determination twice the weight of a single one—we have the following series of data for the ratio in question:

From 1	66.090
From 2	66.124
	66.124
From 3	66.110
	66.110
From 4	66.104
	66.104
From 5	66.099
From 6	66.104
	66.104
From 7	66.129
	66.129
From 8	66.113
	Mean, 66.111 ± .0023

Hence, from Marignac's work, $4Ag : K_2ZnCl_4 :: 100 : 66.111 \pm .0023$, a ratio which can be discussed along with others at the close of this chapter. It corresponds to Zn = 65.245.

During the years between 1883 and 1889, a number of determinations were made of the direct ratio between zinc and hydrogen—that is, weighed quantities of zinc were dissolved in acid, the hydrogen evolved was measured, and from its volume, with Regnault's data, the weight of H was computed. First in order are Van der Plaats' determinations,[1] whose results, as given by himself, are subjoined. The weights are reduced to a vacuum. Sulphuric acid was the solvent:

Zn, grm.	*H, litres.*	*Zn =*
6.6725	1.1424	65.21
9.1271	1.5643	65.14
13.8758	2.3767	65.18
		Mean, 65.177 ± .0137

With the new value for the weight of hydrogen, 0.89872 gramme per liter, this becomes Zn 64.980 ± .0137, when H = 1.

[1] Compt. Rend., 100, 52. 1885.

Reynolds and Ramsay made 29 determinations of this ratio,[1] rejecting, however, all but 5. The weighings were reduced to vacuum, and in each experiment the volume of hydrogen was fixed by the mean of seven or eight readings. The values for Zn are as follows:

65.5060	65.5522
65.4766	65.4141
65.4450	

Mean, 65.4787 ± .0161

These values were computed with Regnault's data for the weight of H. Corrected by the new value the mean becomes Zn = 65.280 ± .0161.

A few determinations by Mallet were made incidentally to his work on the atomic weight of gold, and appear in the same paper.[2] According to these experiments one gramme of zinc gives—

341.85	cc. H.,	and Zn=	65.158
341.91	"	"	65.146
341.93	"	"	65.143
342.04	"	"	65.122

Mean, 65.142 ± .0039

In this case the Crafts-Regnault weight of H was taken, 1 liter = .08979 gramme. Corrected, the mean gives Zn = 65.082 ± .0039.

Two other series of determinations of questionable value remain to be noticed before leaving the consideration of the direct H : Zn ratio. They represent really the practice work of students, and are interesting as an illustration of the closeness with which such work can be done. The first series was made in the laboratory of the Johns Hopkins University, under the direction of Morse and Keiser,[3] and contains 51 determinations, as follows:

	Zn=	
64.68	65.74	65.40
65.26	64.72	64.80
65.32	65.26	65.20
65.20	64.74	64.40
65.60	64.72	65.00
64.60	65.10	64.40
65.00	64.76	65.24
65.68	64.90	64.60
65.38	64.92	64.80
65.06	64.64	65.14
64.84	65.24	64.84
64.88	64.72	64.82
65.00	65.20	64.80
65.08	65.12	64.40
65.06	66.40	64.60
64.74	64.60	64.80
65.12	65.60	64.74

Mean of all, Zn = 64.997 ± .0328

Corrected for the difference between Regnault's value for H and the new value, this becomes Zn = 64.800 ± .0328.

The second student series was published by Torrey,[4] who gives 15 determinations, as follows:

Zn=	
65.36	64.96
65.30	64.70
64.92	65.00
64.72	64.78
65.04	64.44
64.80	65.24
65.20	64.92
64.90	

Mean, 64.952 ± .0436

Corrected as in the other series, this gives Zn = 64.755 ± .0436.

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[1] Journ. Chem. Soc., 51, 854. 1887.
[2] Amer. Chem. Journ., 12, 205. 1890.
[3] Amer. Chem. Journ., 6, 347. 1884.
[4] Amer. Chem. Journ., 10, 74. 1888.

The five corrected means for the ratio H : ZN may now be combined, thus:

	H=1.	*O=16.*
Van der Plaats	64.980±.0137	65.487
Reynolds and Ramsay	65.280±.0161	65.789
Mallet	65.081±.0039	65.590
Morse and Keiser	64.800±.0328	65.305
Torrey	64.755±.0036	65.260
General mean	65.079±.0036	65.587±.0036

Morse and Burton,[1] in their determinations of the atomic weight of zinc, returned essentially to the old method adopted by Erdmann and by Jacquelain. Their zinc was obtained spectroscopically pure by distillation in a vacuum, and was oxidized by nitric acid which left absolutely no residue upon evaporation. The conversion to oxide was effected in a porcelain crucible, which was inclosed in a larger one, and the ignition of the nitrate was carried out in a muffle. In weighing the crucible was tared by one of nearly equal weight. Results as follows:

Wt. Zn.	*Wt. ZnO.*	*Per cent Zn in ZnO.*
1.11616	1.38972	80.320
1.03423	1.28782	80.308
1.11628	1.38987	80.315
1.05760	1.31681	80.316
1.04801	1.30492	80.313
1.02957	1.28193	80.318
1.09181	1.35944	80.315
1.16413	1.44955	80.305
1.07814	1.34248	80.305
1.12754	1.40400	80.306
.91112	1.13446	80.310
1.10011	1.36981	80.311
1.17038	1.45726	80.313
1.03148	1.28436	80.310
1.05505	1.31365	80.308
	Mean,	80.3115±.00084

Hence, Zn = 65.266.

Morse and Burton verified by experiment the stability of oxide of zinc at the temperatures of ignition, and found that it did not dissociate. They also proved the absence of oxides of nitrogen from the zinc oxide. The investigations of Richards and Rogers,[2] however, have shown that zinc oxide prepared by ignition of the nitrate always carries gaseous occlusions, so that the atomic weight of zinc computed from the data of Morse and Burton is certainly too low. This consideration led Morse and Arbuckle [3] to reinvestigate zinc oxide, with the purpose of avoiding the indicated error. The zinc used was a portion of the sample employed by Morse and Burton, and the process was essentially the same, except that the oxide, after weighing, was dissolved in sulphuric acid, and the gases which were evolved were collected, measured, and analyzed. All weights were corrected for displacement of air. The crude data are as follows:

Wt. Zn.	*Wt. ZnO.*	*Gases, cc.*	*Per cent Zn, uncorrected.*
1.19573	1.48860	.468	80.326
1.03381	1.28707	.402	80.323
1.06519	1.32599	.342	80.332
1.05802	1.31711	.312	80.329
1.26618	1.57619	.521	80.332
1.03783	1.29198	.408	80.329
1.08655	1.35276	.412	80.321
1.11364	1.38647	.456	80.322
		Mean,	80.327±.0011

[1] Amer. Chem. Journ., 10, 311. 1888.
[2] Proc. Amer. Acad., 1893, 200.
[3] Amer. Chem. Journ., 20, 1898. Also published as a doctoral dissertation, Johns Hopkins University, by Arbuckle.

The collected gases contained only nitrogen and oxygen, in varying proportions, which were determined in each case. Uncorrected, Zn = 65.328; corrected, the value ranged between 65.437 and 65.489, in mean, 65.456. The last figure corresponds to 80.358 per cent of zinc in the oxide, an increase of 0.031. If we assume that the same proportional error existed in all the other experiments upon zinc oxide, the several series may be corrected and combined as follows:

Jacquelain	80.572 ± .0070
Erdmann	80.291 ± .0037
Morse and Burton	80.343 ± .00084
Morse and Arbuckle	80.358 ± .0011
General mean	80.349 ± .00065

Here the two earlier series practically disappear, and the modern determinations alone are retained.

The determinations made by Gladstone and Hibbard [1] represent still another process for measuring the atomic weight of zinc. Zinc was dissolved in a voltameter, and the same current was used to precipitate metallic silver or copper in equivalent amount. The weight of zinc dissolved, compared with the weight of the other metal throw down, gives the atomic weight sought for. Two voltameters were used in the experiments, giving duplicate estimates for zinc with reference to each weighing of silver or copper. The silver series is as follows, with the ratio 2Ag : Zn : : 100 : x in the third column:

Zn.	*Ag.*	*Ratio.*
.7767	2.5589	30.353
.7758	2.5589	30.318
.5927	1.9551	30.316
.5924	1.9551	30.300
.2277	.7517	30.291
.2281	.7517	30.345
.7452	2.4588	30.307
.7475	2.4588	30.401
.8770	2.9000	30.241
.8784	2.9000	30.290
.9341	3.0809	30.319
.9347	3.0809	30.339
		Mean, 30.318 ± .0077

Hence, Zn = 65.414.

To the copper series I add the ratio Cu : Zn : : 100 : x:

Zn.	*Cu.*	*Ratio.*
.7767	.7526	103.13
.7758	.7526	103.08
.5927	.5737	103.31
.5924	.5737	103.26
.2277	.2209	103.08
.2281	.2209	103.26
.8770	.8510	103.05
.8784	.8510	103.22
.9341	.9038	103.36
.9347	.9038	103.42
		Mean, 103.22 ± .0261

Hence, Zn = 65.601.

Richards and Rogers,[2] in their investigation of the atomic weight of zinc, studied the anhydrous bromide. This was prepared by solution of zinc oxide in hydrobromic acid, evaporation to dryness, and subsequent distillation in an atmosphere of carbon dioxide. In some experiments, however, the bromide was heated in an atmosphere of nitrogen, mingled with gaseous hydrobromic acid. All water can thus be removed without formation of oxybromides.

[1] Journ. Chem. Soc., 55, 443. 1889.

[2] Zeitsch. anorg. Chem., 10, 1. 1895.

The zinc bromide so obtained was dissolved in water and precipitated with a solution containing a known amount of silver in the form of nitrate. The silver bromide was weighed on a Gooch crucible, and the ratio $2AgBr : ZnBr_2$ thus found. An excess of silver was always used, and in one series of experiments it was estimated by precipitation with hydrobromic acid. Deducting the excess thus found from the original quantity of silver, the amount of the latter proportional to the zinc bromide was found; hence the ratio $2Ag: ZnBr_2$. The results with vacuum weights are as follows:

Series A.

$ZnBr_2$.	*AgBr.*	*Ratio.*
1.69616	2.82805	59.976
1.98198	3.30450	59.978
1.70920	2.84949	59.984
2.35079	3.91941	59.978
2.66078	4.43751	59.961
		Mean, 59.975±.0034

Series B.

$ZnBr_2$.	*Ag.*	*AgBr.*	*Ag Ratio.*	*Ag Br Ratio.*
2.33882	2.24063	3.90067	104.382	59.959
1.97142	1.88837	3.28742	104.398	59.969
2.14985	2.05971	3.58539	104.376	59.961
2.00966	1.92476	3.35074	104.411	59.977
			Mean, 104.392 ±.0054	Mean, 59.967 ±.0027

At the end of the same paper Richards alone gives two more series of determinations made upon zinc bromide prepared by the action of pure bromine upon pure electrolytic zinc. The bromide so obtained was further refined by sublimation or distillation and dried by heating in a stream of carbon dioxide and gaseous hydrobromic acid. Thus was insured the absence of basic salts and water. The weights and results found in the two series were as follows:

Series C.

$ZnBr_2$.	*Ag.*	*Ratio.*
6.23833	5.09766	104.379
5.26449	5.0436	104.380
9.36283	8.9702	104.377
		Mean, 104.379±.0007

Series D.

$ZnBr_2$.	*AgBr.*	*Ratio.*
2.65847	4.43358	59.962
2.30939	3.85149	59.961
5.26449	8.77992	59.961
		Mean, 59.961±.0004

In some details of manipulation these series differ from those given by Richards and Rogers jointly, but their minutiæ are not essential to the present discussion.

Combining these several series, we have—

For $2Ag : ZnBr_2 : : 100 : x$.

Series B	104.392±.0054
Series C	104.379±.0007
General mean	104.380±.0007

For $2AgBr : ZnBr_2 : : 100 : x$.

Series A	59.975±.0034
Series B	59.967±.0027
Series D	59.961±.0004
General mean	59.962±.0004

From the Ag ratio, Zn = 65.364.

From the AgBr ratio, Zn = 65.375.

And Ag : Br : : 100 : 74.077.

In order to determine the atomic weight of zinc, Meaglia[1] measured the direct ratios between that metal and silver or gold. The silver was precipitated from a sulphate solution by zinc, and the gold from a solution of sodium chloraurate. From the weights obtained the following values for zinc were computed, when Ag = 107.93 and Au = 197.2.

Silver Series.	*Gold Series.*
65. 58	65. 509
65. 45	65. 424
65. 50	65. 440
65. 41	65. 470
Mean, 65. 485 ± . 0247	Mean, 65. 436 ± —. 0087

From the silver ratio, with Ag = 107.88, Zn = 65.455.

From the gold ratio, with Au = 197.209, Zn = 65.439.

For the ratio 2Ag : Zn, Gladstone and Hibbert's data give the value 30.318 ± .0077. Meaglia's figures, reduced to the same basis, give 30.337 ± .0115. The two series combined give

$$2Ag : Zn : : 100 : 30.324 \pm .0064$$

There is also a single measurement of the silver-zinc ratio by Pecheux,[2] who finds Zn = 65.44 when Ag = 107.88. As no details are given this value can not be utilized here.

A different electrolytic determination of the atomic weight of zinc has been made by Baxter and Grose,[3] who subjected zinc bromide to electrolysis, and collected the zinc in a weighed mercury cathode. Their data, with vacuum weights, are as follows:

$ZnBr_2$.	*Zn.*	*Per cent Zn.*
6. 88781	1. 99917	29. 025
6. 79973	1. 97324	29. 019
7. 67096	2. 22712	29. 030
8. 02839	2. 33122	29. 037
7. 18458	2. 08517	29. 023
7. 55005	2. 19181	29. 030
7. 71332	2. 23937	29. 032
7. 11551	2. 06599	29. 035
7. 44099	2. 16047	29. 035
7. 18828	2. 08727	29. 037
		Mean, 29. 030 ± . 0013

Hence, Zn = 65.384.

Baxter and Grose reject the first two determinations in this series, which raises the percentage of zinc to 29.032. This is equivalent to an atomic weight of Zn = 65.392, an appreciable difference from the value given by the entire series.

For computing the atomic weight of zinc we now have the subjoined ratios:

(1) $ZnO : Zn :: 100 : 80.349 \pm .00065$
(2) $ZnSO_4 : ZnO :: 100 : 50.413 \pm .0020$
(3) $H_2O : Zn :: 100 : 366.319 \pm .088$
(4) $2CO_2 : ZnO :: 100 : 93.169 \pm .012$
(5) $H : Zn :: 1 : 65.079 \pm .0036$
(6) $4Ag : K_2ZnCl_4 :: 100 : 66.111 \pm .0023$
(7) $2Ag : Zn :: 100 : 30.324 \pm .0060$
(8) $Cu : Zn :: 100 : 103.22 \pm .0261$
(9) $2Ag : ZnBr_2 :: 100 : 104.38 \pm .0007$
(10) $2AgBr : ZnBr_2 :: 100 : 59.962 \pm .0004$
(11) $Au : Zn :: 197.2 : 65.436 \pm .0087$
(12) $ZnBr_2 : Zn :: 100 : 29.030 \pm .0034$.

[1] Thesis, University of Grenoble, 1907. [2] Compt. Rend., 154, 1419. 1912. [3] Journ. Amer. Chem. Soc., 38, 868. 1916.

The values used in reducing these ratios are:

Ag=107.880±.00016	C=12.0025±.00019
Cl=35.4605±.00011	K=39.0975±.00011
Br=79.9228±.00015	Cu=63.555 ±.00050
S=32.0650±.00012	Au=197.209 ±.0029
H=1.0078±.00001	

Hence,

From ratio:	
6	Zn=65.245±.0100
9	65.364±.0016
10	65.375±.0022
12	65.384±.0034
2	65.399±.0046
1	65.421±.00044
7	65.427±.0129
11	65.439±.0088
5	65.587±.0036
8	65.601±.0166
4	65.993±.0106
3	65.995±.0159
General mean	Zn=65.397±.0004

CADMIUM.

The earliest determination of the atomic weight of this metal was by Stromeyer, who found that 100 parts of cadmium united with 14.352 of oxygen.[1] Hence Cd=111.483. This value has now only a historical interest.

The more modern estimates of the atomic weight of cadmium begin with the work of v. Hauer.[2] He heated pure anhydrous cadmium sulphate in a stream of dry hydrogen sulphide, and weighed the cadmium sulphide thus obtained. His results were as follows, with the percentage of CdS in $CdSO_4$ therefrom deduced:

$CdSO_4$	*CdS.*	*Per cent.*
7.7650	5.3741	69.209
6.6086	4.5746	69.222
7.3821	5.1117	69.245
6.8377	4.7336	69.228
8.1956	5.6736	69.227
7.6039	5.2634	69.220
7.1415	4.9431	69.217
5.8245	4.0335	69.251
6.8462	4.7415	69.257
		Mean, 69.231±.0042

Hence Cd=111.937.

Lenssen[3] worked upon pure cadmium oxalate, handling, however, only small quantities of material. This salt, upon ignition, leaves the following percentages of oxide:

Oxalate.	*CdO.*	*Per cent.*
0.5128	0.3281	63.982
.6552	.4193	63.996
.4017	.2573	64.053
		Mean, 64.010±.014

Hence Cd=112.064.

Dumas[4] dissolved pure cadmium in hydrochloric acid, evaporated the solution to dryness, and fused the residue in hydrochloric acid gas. The cadmium chloride thus obtained was dissolved in water and titrated with a solution of silver after the usual manner.

[1] See Berz. Lehrbuch, 5th Aufl., 3, 1219.
[2] Journ. prakt. Chem., 72, 350. 1857.
[3] Journ. prakt. Chem., 79, 281. 1860.
[4] Ann. Chem. Pharm., 113, 27. 1860.

From Dumas' weighings I calculate the ratio between $CdCl_2$ and 100 parts of silver:

$CdCl_2$.	*Ag.*	*Ratio.*
2. 369	2. 791	84. 880
4. 540	5. 348	84. 892
6. 177	7. 260	85. 083
2. 404	2. 841	84. 618
3. 5325	4. 166	84. 794
4. 042	4. 767	84. 791
		Mean, 84. 843 ± .0260

Hence, Cd = 112.14.

Next in order comes Huntington's [1] work, carried out in the laboratory of J. P. Cooke. Bromide of cadmium was prepared by dissolving the carbonate in hydrobromic acid, and the product, dried at 200°, was purified by sublimation in a porcelain tube. Upon the compound thus obtained two series of experiments were made.

In one series the bromide was dissolved in water, and a quantity of silver not quite sufficient for complete precipitation of the bromine was then added in nitric acid solution. After the precipitate had settled, the supernatant liquid was titrated with a standard solution of silver containing one gramme to the litre. The precipitate was washed by decantation, collected by reverse filtration and weighed. To the weighings I append the ratio betweeen $CdBr_2$ and 100 parts of silver bromide:

$CdBr_2$.	*AgBr.*	*Ratio.*
1. 5592	2. 1529	72. 423
*3. 7456	5. 1724	72. 415
2. 4267	3. 3511	72. 415
*3. 6645	5. 0590	72. 435
*3. 7679	5. 2016	72. 437
2. 7938	3. 8583	72. 410
*1. 9225	2. 6552	72. 405
3. 4773	4. 7593	72. 433
		Mean, 72. 4216 ± .0028

Hence, Cd = 112.17.

The second series was like the first, except that the weight of silver needed to effect precipitation was noted, instead of the weight of silver bromide formed. In the experiments marked with an asterisk, both the amount of silver required and the amount of silver bromide thrown down were determined in one set of weighings. The third column gives the $CdBr_2$ proportional to 100 parts of silver:

$CdBr_2$.	*Ag.*	*Ratio.*
*3. 7456	2. 9715	126. 051
5. 0270	3. 9874	126. 072
*3. 6645	2. 9073	126. 045
*3. 7679	2. 9888	126. 067
*1. 9225	1. 5248	126. 082
2. 9101	2. 3079	126. 093
3. 6510	2. 8951	126. 110
3. 9782	3. 1551	126. 088
		Mean, 126. 076 ± .0052.

Hence, Cd = 112.18.

According to Huntington's own calculations, these experiments fix the ratio between silver, bromine, and cadmium as Ag : Br: Cd :: 108:80:112.31.

In 1890, Partridge [2] published determinations of the atomic weight of cadmium, made by three methods, the weighings being reduced to a vacuum standard throughout. First, Lenssen's method was followed, viz, the ignition of the oxalate, with the subjoined results:

CdC_2O_4.	*CdO.*	*Per cent CdO.*
1. 09898	. 70299	63. 966
1. 21548	. 77746	63. 962

[1] Proc. Amer. Acad., 17, 28. 1881.

[2] Amer. Journ. Sci. (3), 40, 377. 1890.

CdC_2O_4.	CdO.	Per cent CdO.
1.10711	0.70807	63.957
1.17948	.75440	63.959
1.16066	.74327	63.959
1.17995	.75471	63.964
1.34227	.85864	63.968
1.43154	.91573	63.970
1.53510	.98197	63.968
1.41311	.90397	63.971
		Mean, 63.964±.0010.

Hence, Cd = 111.809.

Secondly, v. Hauer's experiments were repeated, cadmium sulphate being reduced to sulphide by heating in a stream of H_2S. The following data were obtained:

$CdSO_4$.	CdS.	Per cent CdS.
1.60514	1.11076	69.204
1.55831	1.07834	69.197
1.67190	1.15669	69.185
1.66976	1.15554	69.200
1.40821	.97450	69.202
1.56290	1.08156	69.205
1.63278	1.12985	69.194
1.58270	1.09524	69.198
1.53873	1.06481	69.201
1.70462	1.17962	69.201
		Mean, 69.199±.0012
		v. Hauer found, 69.231±.0042
		General mean, 69.202±.0012

The Partridge series alone gives Cd = 111.721.

In the third set of determinations cadmium oxalate was transformed to sulphide by heating in H_2S, giving the ratio $Cd_2CO_4 : CdS :: 100 : x$:

Cd_2CO_4.	CdS.	Per cent CdS.
1.57092	1.13065	71.972
1.73654	1.24979	71.973
2.19276	1.57825	71.974
1.24337	.89492	71.974
1.18743	.85463	71.975
1.54038	1.10858	71.968
1.38905	.99974	71.976
2.03562	1.46517	71.979
2.03781	1.46658	71.970
1.91840	1.38075	71.971
		Mean, 71.973±.0007

Hence, Cd = 111.59.

This work of Partridge was presently discussed by Clarke,[1] with reference to the concordance of the data, and it was shown that the three ratios determined could be discussed algebraically, giving values for the atomic weights of Cd, S and C when O = 16. These values are

$$\begin{aligned} Cd &= 111.7850 \\ C &= 11.9958 \\ S &= 32.0002 \end{aligned}$$

and are independent of all antecedent values except that assumed for the standard, oxygen.

Morse and Jones,[2] starting with cadmium purified by fractional distillation in vacuo adopted two methods for their determinations. First, they effected the synthesis of the oxide from known weights of metal by dissolving the latter in nitric acid, evaporating to dryness, and subsequent ignition of the product. The oxide thus obtained was thought to be completely

[1] Amer. Chem. Journ., 13, 34. 1891.

[2] Amer. Chem. Journ., 14, 261. 1892.

free from oxides of nitrogen. The weighings, which are given below, were made in tared crucibles. The third column gives the percentage of Cd in CdO:

Cd taken.	*CdO found.*	*Per cent Cd.*
1.77891	2.03288	87.507
1.82492	2.08544	87.508
1.74688	1.99626	87.507
1.57000	1.79418	87.505
1.98481	2.26820	87.506
2.27297	2.59751	87.504
1.75695	2.00775	87.508
1.70028	1.94305	87.505
1.92237	2.19679	87.508
1.92081	2.19502	87.508
		Mean, 87.5066±.00032

Hence, Cd = 112.068.

The second method employed by Morse and Jones was that of Lenssen with cadmium oxalate. This salt they found to be somewhat hygroscopic, a property against which the operator must be on his guard. The data found are as follows:

CdC_2O_4.	*CdO.*	*Per cent CdO.*
1.53937	.98526	64.004
1.77483	1.13582	63.996
1.70211	1.08949	64.008
1.70238	1.08967	64.004
1.74447	1.11651	64.003
		Mean, 64.003±.0042

Hence, Cd = 112.03

Lorimer and Smith,[1] like Morse and Jones, determined the atomic weight of cadmium by means of the oxide, but by analysis instead of synthesis. Weighed quantities of oxide were dissolved in potassium cyanide solution, from which metallic cadmium was thrown down electrolytically. The weights are reduced to a vacuum standard:

CdO taken.	*Cd found.*	*Per cent Cd.*
.34767	.30418	87.491
.41538	.36352	87.515
1.04698	.91618	87.507
1.04066	.91500	87.493
1.26447	1.10649	87.506
.78493	.68675	87.492
.86707	.75884	87.518
.67175	.58785	87.510
1.44362	1.26329	87.508
		Mean, 87.5044±.0023

Hence, Cd = 112.042.

Mr. Bucher's dissertation[2] upon the atomic weight of cadmium does not claim to give any final measurements, but rather to discuss the various methods by which that constant has been determined. Nevertheless, it gives many data which seem to have positive value, and which are certainly fit for discussion along with those which have preceded this paragraph. Bucher began with cadmium purified by distillation nine times in vacuo, and from this his various compounds were prepared. His first series of determinations was made by reducing cadmium oxalate to oxide, the oxalate having been dried fifty hours at 150°. The reduction was effected by heating in jacketed porcelain crucibles, with various precautions, and the results obtained, reduced to a vacuum, are as follows:

Oxalate.	*Oxide.*	*Per cent oxide.*
1.97674	1.26414	63.951
1.94912	1.24682	63.968
1.96786	1.25886	63.971

[1] Zeitsch. anorg. Chem., 1, 364. 1892.

[2] "An examination of some methods employed in determining the atomic weight of cadmium." Johns Hopkins University doctoral dissertation. By John E. Bucher. Baltimore, 1895.

Oxalate.	*Oxide.*	*Per cent oxide.*
1.87099	1.19675	63.958
1.37550	.87994	63.972
1.33313	.85308	63.991
1.94450	1.24452	64.002
2.01846	1.29210	64.014
		Mean, 63.978±.0052

Hence, Cd = 111.89.

Combing this with the means found by previous experimenters, we have for the percentage of oxide in oxalate—

Lenssen	64.010±.0140
Partridge	63.964±.0010
Morse and Jones	64.003±.0042
Bucher	63.978±.0052
General mean	63.966±.0010

Bucher's next series of determinations was by Partridge's method—the conversion of cadmium oxilate into cadmium sulphide by heating in a stream of sulphuretted hydrogen. The sulphide was finally cooled in a current of dry nitrogen. The vacuum weights and ratios are subjoined:

Oxalate.	*Sulphide.*	*Percentage.*
2.56319	1.84716	72.065
2.18364	1.57341	72.055
2.11643	1.52462	72.037
3.13105	2.25582	72.047
		Mean, 72.051±.0127
		Partridge found, 71.973±.0007
		General mean, 71.974±.0007

Here Bucher's mean practically vanishes. Taken alone, it gives Cd = 112.14.

The third method employed by Bucher was that of weighing cadmium chloride, dissolving in water, precipitating with silver nitrate, and weighing the silver chloride found. The cadmium chloride was prepared, partly by solution of cadmium in hydrochloric acid, evaporation to dryness, and sublimation in vacuo; and partly by the direct union of the metal with chlorine. The silver chloride was weighed in a Gooch crucible, with platinum sponge in place of the asbestos. To the vacuum weights I append the ratio $2AgCl : CdCl_2 : : 100 : x$.

$CdCl_2$.	*$AgCl$.*	*Ratio.*
3.09183	4.83856	63.900
2.26100	3.53854	63.896
1.35729	2.12431	63.893
2.05582	3.21727	63.899
1.89774	2.97041	63.886
3.50367	5.48473	63.880
2.70292	4.23087	63.886
4.24276	6.63598	63.936
3.40200	5.32314	63.910
4.60659	7.20386	63.946
2.40832	3.76715	63.930
2.19144	3.42724	63.942
2.84628	4.45477	63.893
2.56748	4.01651	63.923
2.31003	3.61370	63.924
1.25008	1.95652	63.893
1.96015	3.06541	63.944
2.29787	3.59391	63.938
1.94227	3.03811	63.915
1.10976	1.73547	63.946
1.63080	2.55016	63.949
		Mean, 63.916±.0032

Hence, Cd = 112.314.

Bucher gives a rather full discussion of the presumable errors in this method, which, however, he regards as somewhat compensatory. The series is followed by a similar one with cadmium bromide, the latter having been sublimed in vacuo. Results as follows:

$CdBr_2$.	*AgBr.*	*Ratio.*
4.39941	6.07204	72.454
3.18030	4.38831	72.472
3.60336	4.97150	72.480
4.04240	5.58062	72.453
3.60505	4.97519	72.461
		Mean, 72.464±.0035

Hence, Cd = 112.33.

In order to fix a minimum value for the atomic weight of cadmium, Bucher effected the synthesis of the sulphate from the metal. 1.15781 grammes of cadmium gave 2.14776 of sulphate.

Hence, Cd = 112.35.

The sulphate produced was dried at 400°, and afterwards examined for free sulphuric acid, giving a correction which was applied to the weighings. The corrected weight is given above. Any impurity in the sulphate would tend to lower the apparent atomic weight of cadmium, and therefore the result is believed by the author to be a minimum.

Finally, Bucher examined the oxide method followed by Morse and Jones. The syntheses of oxide were effected in double crucibles, first with both crucibles porcelain, and afterwards with the small inner crucible of platinum. Two experiments were made by the first method, three by the last. Weights and percentages (Cd in CdO) as follows:

Cd.	*CdO.*	*Percentage.*
1.26142	1.44144	87.511
.99785	1.14035	87.504
		Mean, 87.5075±.0024

Cd.	*CdO.*	*Percentage.*
1.11321	1.27247	87.484
1.02412	1.17054	87.491
2.80966	3.21152	87.487
		Mean 87.4873±.0016

The two means given above, representing work done with porcelain and with platinum crucibles, correspond to a difference of about 0.2 in the atomic weight of cadmium. Experiments were made with pure oxide of cadmium by converting it into nitrate and then back to oxide, exactly as in the foregoing syntheses. In each case the oxide obtained at the end of the operation represented an increase in weight, but the increase was greater in platinum than in porcelain. Hence the weighings of cadmium oxide in the foregoing determinations are subject to constant errors, and cannot be trusted to fix the atomic weight of cadmium.

A different class of determinations relative to the atomic weight of cadmium are those of Hardin,[1] who effected the electrolysis of the chloride and bromide, and also made a direct comparison between cadmium and silver. The aqueous solutions of the salts, mixed with potassium cyanide, were electrolyzed in platinum dishes. The cadmium which served as the starting point for the investigation was purified by distillation in hydrogen. All weights are reduced to a vacuum. The data for the chloride series are as follows, with a column added for the percentage of Cd in $CdCl_2$:

Weight $CdCl_2$.	*Weight Cd.*	*Per cent Cd.*
0.43140	0.26422	61.247
.49165	.30112	61.247
.71752	.43943	61.241
.72188	.44208	61.241
.77264	.47319	61.245

[1] Journ. Amer. Chem. Soc., 18, 1016. 1896.

Weight $CdCl_2$.	*Weight Cd.*	*Per cent Cd.*
.81224	.49742	61.240
.90022	.55135	61.246
1.02072	.62505	61.236
1.26322	.77365	61.244
1.52344	.93314	61.252
		Mean, 61.244±.0010

Hence, Cd = 112.07.

The results for the bromide, similarly stated, are these:

Weight $CdBr_2$	*Weight Cd.*	*Per cent Cd.*
0.57745	0.23790	41.198
.76412	.31484	41.203
.91835	.37842	41.207
1.01460	.41808	41.206
1.15074	.47414	41.203
1.24751	.51392	41.196
1.25951	.51905	41.210
1.51805	.62556	41.208
1.63543	.67378	41.199
2.15342	.88722	41.200
		Mean, 41.203±.0010

Hence, Cd = 112.01.

The direct comparison of cadmium and silver was effected by the simultaneous electrolysis, in the same current, of double cyanide solutions. Silver was thrown down in one platinum dish and cadmium in another. The process was not altogether satisfactory, and gave divergent results, those which are cited below having been selected by Hardin from the mass of data obtained. I have added in a third column the cadmium proportional to 100 parts of silver:

Weight Cd.	*Weight Ag.*	*Ratio.*
0.12624	0.24335	51.876
.11032	.21262	51.886
.12720	.24515	51.887
.12616	.24331	51.852
.22058	.42520	51.877
		Mean, 51.876±.0041

Hence, Cd = 111.93.

The work of Morse and Arbuckle[1] upon the atomic weight of cadmium was similar in character and purpose to their work upon zinc. The presence of occluded gases in the oxide was recognized, and in the new determinations they were extracted, measured, and analyzed. Cadmium was converted into oxide, and corrections for the gaseous impurities were applied. The vacuum weights of metal and oxide are given below, together with the volume of extracted gas, and the crude, *uncorrected* percentage of Cd in CdO:

Weight Cd.	*Weight CdO.*	*Gas cc.*	*Per cent.*
1.931882	2.207639	0.574	87.509
1.679348	1.919096	.480	87.507
1.484296	1.696195	.441	87.507
1.364861	1.559717	.402	87.507
1.502948	1.717441	.419	87.511
1.438035	1.643297	.431	87.509
1.440410	1.646037	.406	87.508
1.459384	1.667714	.421	87.508
1.403791	1.604196	.390	87.507
			Mean, 87.508±.0003

This gives Cd = 112.082. Corrected for occluded gases, Cd = 112.377 in mean, ranging from 112.359 to 112.395. The correction adds 0.029 to the percentage of metal; and if we assume the same correction to the older determinations of this ratio, the several series combine as follows.

[1] Amer. Chem. Journ., 20, 536. 1898. See also Arbuckle, Thesis, Johns Hopkins University, 1898.

Morse and Jones	87.5356±.0003
Lorimer and Smith	87.5334±.0023
Bucher, 1	87.5365±.0024
Bucher, 2	87.5163±.0016
Morse and Arbuckle	87.5370±.0003
General mean	87.5360±.0002

This combination is equivalent to a rejection of all the data except those of Morse and his colleagues.

Baxter and Hines,[1] in order to determine the atomic weight of cadmium, resorted to the analysis of the chloride, with all the precautions characteristic of the Harvard laboratory. First, the gravimetric ratio 2AgCl: $CdCl_2$ was determined, with the subjoined results. Vacuum weights are given throughout:

Weight $CdCl_2$	*Weight AgCl.*	*Ratio.*
5.53421	8.65356	63.953
7.77758	12.16166	63.952
8.87917	13.88344	63.955

Secondly, the ratio 2Ag : $CdCl_2$ was measured by adding to the solution of the cadmium salt as nearly as possible its exact equivalent of a standard silver solution, and then determining the slight excess of silver or chlorine by titration. The results are as follows:

Weight $CdCl_2$.	*Weight Ag.*	*Ratio.*
4.92861	5.80063	84.967
3.86487	4.54891	34.963
5.08551	5.98569	84.961
5.84335	6.87704	84.969
5.99952	7.06084	84.969
3.73092	4.39095	84.968

A year later, the same ratios were remeasured by Baxter, Hines, and Frevert.[2] I subjoin their data:

Weight $CdCl_2$.	*Weight Ag.*	*Weight AgCl.*	*Ag ratio.*	*AgCl ratio.*
5.62500	6.61993	.....	84.972	.....
6.81031	8.01496	10.64918	84.970	63.9515
5.50089	6.47393	8.60174	84.970	63.9509
6.11750	.....	9.56590	.....	63.9511

These series are so nearly identical and so short that it seems well to treat both investigations as one. On this basis, 2Ag : $CdCl_2$ :: 100 : 84.9677, ±.0008, and 2AgCl : $CdCl_2$ :: 100 : 63.9523, ±.0004.

Hence, from the Ag ratio, Cd = 112.41.

From the AgCl ratio, Cd = 112.42.

And Ag : Cl :: 100 : 32.861.

Baxter, Hines and Frevert also made analyses of cadmium bromide by the usual Harvard methods. Their data follow:

Weight $CdBr_2$.	*Weight Ag.*	*Weight AgBr.*	*Ag ratio.*	*AgBr ratio.*
11.46216	9.08379	15.81319	126.182	72.485
6.82282	5.40724	9.41267	126.182	72.486
6.75420	5.35277	9.31830	126.181	72.483
7.08588	5.61597	9.77649	126.174	72.479
5.13859	4.07226	7.08933	126.183	72.483
5.84324	4.63072	8.06130	126.183	72.485
5.99704	4.75259	8.27360	126.183	72.484
5.90796	4.68200	8.15070	126.183	72.484
			Mean, 126.181	72.4836
			±.0009	±.0005

From the Ag ratio, Cd = 112.40.

[1] Journ. Amer. Chem. Soc., 27, 222. 1905.

[2] Journ. Amer. Chem. Soc., 28, 770. 1906.

From the AgBr ratio, Cd = 112.41.

And Ag : Br : : 100 : 74.082.

The four ratios determined by Baxter and his colleagues may now be combined with the earlier determinations, as follows:

Ratio 2Ag : $CdCl_2$: : 100 : x.

Dumas	84.843 ±.0260
Baxter, etc	84.9677±.0008
General mean	84.9677±.0008

Ratio 2AgCl : $CdCl_2$: : 100 - x.

Bucher	63.916 ±.0032
Baxter, etc	63.9523±.0004
General mean	63.9518±.0004

Ratio 2Ag : $CdBr_2$: : 100 : x.

Huntington	126.076±.0052
Baxter, etc	126.181±.0009
General mean	126.178±.0009

Ratio 2 AgBr : $CdBr_2$: : :100 : x.

Huntington	72.4216±.0028
Bucher	72.464 ±.0035
Baxter, etc	72.4836±.0005
General mean	72.4813±.0005

The earlier determinations of these four ratios practically vanish.

The determinations of the atomic weight of cadmium by Meaglia [1] were based upon the quantitative precipitation by that metal of silver from a sulphate solution, and gold from a solution of sodium chloraurate. With Ag = 107.93 and Au = 197.2 the following values for cadmium were obtained:

Silver series.	*Gold series.*
112.37	112.41
112.56	121.45
112.45	112.65
112.38	112.47
	112.48
Mean, 112.44±.0295	112.40
	112.42
	112.41
	Mean, 112.461±.0196

From the silver series, with Ag = 107.88, Cd = 112.39.

From the gold series, with Au = 197.209, Cd = 112.46.

The determinations made by Blum [2] depended upon the conversion of CdO into CdS by heating in a stream of hydrogen sulphide. His figures, with vacuum weights, are given below, together with the ratio CdO : CdS : : 100 : x:

CdO.	*CdS.*	*Ratio.*
1.80552	2.03108	112.493
.66349	.74617	112.461
1.82460	2.05256	112.494
1.88424	2.11974	112.498
3.59206	4.04081	112.493
4.38093	4.92695	112.464
		Mean, 112.484±.0046

Hence Cd = 112.69. This ratio is not of much value.

In 1911 Perdue and Hulett [3] proposed a new method for the electrolytic determination of atomic weights, and in a second paper [4] applied it to the analysis of cadmium sulphate,

[1] Thesis, University of Grenoble, 1907.
[2] Thesis, University of Pennsylvania, 1908.
[3] Journ. Phys. Chem., 15, 146. 1911.
[4] Ibid., p. 155.

$3CdSO_4.8H_2O$. The method, briefly, consisted in the electrolysis of a salt containing a metal soluble in mercury, and in collecting the metal on a weighed mercury cathode. With cadmium sulphate the electrolysis was preceded by a careful determination of the water in the hydrated salt. With vacuum weights the figures for the water series are as follows:

$3CdSO_4.8H_2O$.	*H_2O.*	*Per cent H_2O.*
6.32863	1.1856	18.734
6.72493	1.25986	18.734
6.87537	1.2886	18.742
5.65027	1.05822	18.729
6.81125	1.27557	18.727
7.34977	1.37703	18.736
7.74837	1.3572	18.727
7.8843	1.47713	18.734
6.6100	1.2480	18.730
		Mean, 18.733±.0011

Hence, Cd = 112.35.

The two electrolytic series, for the hydrated and anhydrous sulphate are as follows:

$3CdSO_4.8H_2O$.	*Cd.*	*Per cent Cd.*
7.90902	3.46335	43.790
9.07468	3.97434	43.796
7.32787	3.20936	43.796
6.48847	2.84186	43.799
5.11684	2.24157	43.808
8.02954	3.51755	43.807
5.08743	2.22827	43.799
		Mean, 43.799±.0024

Hence, Cd = 112.31.

$CdSO_4$.	*Cd.*	*Per cent Cd.*
5.14303	2.77196	53.897
5.46507	2.94566	53.898
5.58667	3.01076	53.891
5.53568	2.98276	53.883
6.29717	3.39295	53.880
6.40718	3.45255	53.887
5.37196	2.89457	53.883
		Mean, 53.888±.0018.

Hence, Cd = 112.256.

The foregoing determinations were promptly criticized by Richards,[1] who suggested that the cadmium sulphate might have retained traces of water, perhaps in "solid solution," which would lead to a low value for the atomic weight of cadmium.

A year later Laird and Hulett[2] applied the new method to the direct comparison of cadmium and silver. The cadmium was deposited in duplicate cells, the silver is only one. Their data follow; with the ratio 2Ag :: 100: x.

Cd.	*Ag.*	*Ratio.*
2.2721	4.3638	52.067
2.2733		52.095
2.3549	4.5225	52.071
2.3534		52.036
2.6637	5.1186	52.040
2.6656		52.077
1.9937	3.8312	52.039
1.9938		52.044
2.2979	4.4148	52.050
2.2972		52.034
2.4265	4.6605	52.065
2.4261		52.057

[1] Journ. Amer. Chem. Soc., 33, 888.

[2] Trans. Amer. Electrochem. Soc., 22, 385. 1912.

Cd.	*Ag.*	*Ratio.*
2.1496	4.1297	52.052
2.1501		52.064
2.6629	5.1256	52.064
2.6675		52.043

Mean, 52.055±.0007.

Hence, Cd = 112.31.

Combining this mean with previous determinations we have—

Hardin	51.876±.0041
Meaglia	52.090±.0136
Laird and Hulett	52.055±.0007
General mean	52.050±.00069

In the following year the investigation was continued by Quinn and Hulett,[1] who made electrolytic analyses of cadmium chloride and bromide. For the chloride the data are as follows:

$CdCl_2$.	*Cd.*	*Per ct. Cd.*	
4.10119	2.51427	61.306	
4.47151	2.74084	61.295	
5.66452	3.47180	61.290	
5.99291	3.67211	61.274	Rejected.
6.52910	4.00219	61.298	
4.87415	2.98785	61.300	
4.88423	2.99384	61.296	

Mean, 61,297±.0010

Hence, Cd = 112.32.

The bromide data are—

$CdBr_2$.	*Cd.*	*Per cent Cd.*
4.95538	2.04468	41.261
4.15801	1.71573	41.263
5.31272	2.19183	41.256
4.55544	1.87940	41.256
4.31525	1.78013	41.252
3.69646	2.34983	41.251
4.47748	1.84754	41.263
8.36276	2.21228	41.253

Mean, 41.257±.0010

Hence, Cd = 112.26.

The arithmetic mean of the six values thus found for cadmium is 112.30, or about one-tenth of a unit lower than the value determined by Baxter and his associates. Because of the doubt thus thrown upon the Harvard determinations Baxter and Hartmann [2] made a series of analyses of cadmium chloride by the method of Hulett and Quinn, but with various precautions against error. For the elaborate details of these analyses the original paper should be consulted. The data, with vacuum weights, are as follows:

Preliminary series.

$CdCl_2$.	*Cd.*	*Per cent Cd.*
6.08570	3.73181	61.321
4.20489	2.57863	61.295
5.36203	3.28817	61.323
7.50512	4.60221	61.321
6.71591	4.11839	61.323
5.91556	3.62753	61.323
6.49323	3.36805	61.313
3.14416	1.92791	61.317
7.58705	4.65173	61.312

[1] Journ. Phys. Chem., 17, 779. 1913.

[2] Journ. Amer. Chem. Soc., 37, 113. 1915.

$CdCl_2$.	Cd.	Per cent Cd.
2.26738	1.39006	61.307
5.93501	3.63962	61.325
6.04122	3.70490	61.327
4.07400	2.49821	61.321
		Mean, 61.318±.0016

Hence, Cd = 112.42.

Final series.

$CdCl_2$.	Cd.	Per cent Cd.
9.00004	5.51879	61.320
6.56891	4.02808	61.320
7.12956	4.37174	61.319
8.57291	5.25679	61.318
7.76294	4.76011	61.320
		Mean, 61.3194±.00027

Hence, Cd = 112.43.

In continuation of this research, Baxter, Grose, and Hartmann [1] made new electrolytic analyses of cadmium chloride, and also a series of similar analyses of the bromide. For the very short chloride series the figures are:

$CdCl_2$.	Cd.	Per cent Cd.
6.49746	3.98430	61.321
6.62682	4.06348	61.319
7.35812	4.51165	61.317
		Mean, 61.319±.0011

Hence, Cd = 112.43.

For the bromide analyses the data are as follows:

$CdBr_2$.	Cd.	Per cent Cd.
16.55613	6.83575	41.287
6.83764	2.82342	41.284
7.16223	2.95696	41.286
8.71886	2.77414	41.289
10.31855	4.26112	41.296
9.40020	3.88142	41.291
8.21123	3.39038	41.290
10.51504	4.34154	41.289
10.22411	4.22157	41.290
10.99613	4.54013	41.288
11.05166	4.56317	41.290
19.67134	8.12244	41.291
		Mean, 41.289±.0008

Hence, Cd = 112.41.

The several series of analyses of cadmium halides may now be combined as follows:

Ratio $CdBr_2$: Cd :: 100 : x.

Hardin	41.203±.0010
Quinn and Hulett	41.257±.0010
Baxter, Grose, and Hartmann	41.289±.0008
General mean	41.255±.00054

Ratio $CdCl_2$: Cd :: 100 : x.

Hardin	61.244 ±.0010
Quinn and Hulett	61.297 ±.0010
Baxter and Hartmann, preliminary	61.318 ±.0016
Baxter and Hartmann, final	61.3194±.00027
Baxter, Grose, and Hartmann	61.319 ±.0011
General mean	61.3137±.00024

[1] Journ. Amer. Chem. Soc., 38, 857. 1916.

The determinations of the atomic weight of cadmium by Oechsner de Coninck and Gérard[1] are of slight importance, but they should not be ignored. Cadmium carbonate was reduced to metal by heating in a stream of hydrogen, with the following results:

$CdCO_3$	Cd.	Per cent Cd.
0.5500	0.3585	65.182
.6050	.3943	65.174
.6600	.4302	65.182
.6171	.4023	65.192
.5445	.3849	65.179
		Mean, $\overline{65.182} \pm .0025$

Hence, Cd = 112.33.

For computing the atomic weight of cadmium the following ratios are now available:

Bucher's single experiment upon the synthesis of the sulphate, although important and interesting, cannot carry weight enough to warrant its consideration in connection with the other ratios, and is therefore not included.

(1) $CdO : Cd :: 100 : 87.536 \pm .0002$.
(2) $CdCO_3 : Cd :: 100 : 65.182 \pm .0025$.
(3) $CdC_2O_4 : CdO :: 100 : 63.966 \pm .0010$.
(4) $CdC_2O_4 : CdS :: 100 : 71.974 \pm .0007$.
(5) $CdO : CdS :: 100 : 112.484 \pm .0046$.
(6) $CdSO_4 : CdS :: 100 : 69.202 \pm .0012$.
(7) $CdSO_4 : Cd :: 100 : 53.888 \pm .0018$.
(8) $3CdSO_4.8H_2O : 3Cd :: 100 : 43.799 \pm .0024$.
(9) $3CdSO_4.8H_2O : 8H_2O :: 100 : 18.733 \pm .0011$.
(10) $2Ag : CdCl_2 :: 100 : 84.9676 \pm .0008$.
(11) $2AgCl : CdCl_2 :: 100 : 63.9518 \pm .0004$.
(12) $2Ag : CdBr_2 :: 100 : 126.178 \pm .0009$.
(13) $2AgBr : CdBr_2 :: 100 : 72.4813 \pm .0005$.
(14) $CdCl_2 : Cd :: 100 : 61.3137 \pm .00024$.
(15) $CdBr_2 : Cd :: 100 : 41.2555 \pm .00054$.
(16) $2Ag : Cd :: 100 : 52.050 \pm .00069$.
(17) $Au : Cd :: 197.2 : 112.461 \pm .0196$.

To reduce these ratios we have

Ag = 107.880 ± .00016	S = 32.0650 ± .00012
Cl = 35.4605 ± .00011	C = 12.0025 ± .00019
Br = 79.9228 ± .00015	Au = 197.209 ± .0029
H = 1.0078 ± .00001	

Hence,

From ratio—	
4	Cd = 111.596 ± .0051
6	111.741 ± .0061
3	111.820 ± .0041
7	112.255 ± .0059
15	112.258 ± .0018
16	112.303 ± .0015
8	112.306 ± .0078
2	112.329 ± .0091
9	112.348 ± .0126
1	112.370 ± .0018
13	112.397 ± .0019
14	112.402 ± .0009
12	112.402 ± .0020
10	112.405 ± .0018
11	112.407 ± .0012
17	112.466 ± .0197
5	112.688 ± .0150
General mean	$\overline{112.360 \pm .0004}$

[1] Compt. Rend., 161, 676. 1915.

Rejection of the first three values raises the general mean to 112.376. The last two values, with their high probable errors, count for practically nothing.

It will be seen, from a comparison of the individual ratios, that the most recent determinations of the atomic weight of cadmium fall into two groups. Those of Hulett and his colleagues are concordant, and give Cd = 112.3 very nearly. Those of Baxter and his associates, on the other hand, are even more closely concordant, and give Cd = 112.4. This disagreement has led to some controversy. The criticism by Richards of the work of Perdue and Hulett has already been noticed, and the electrolytic determination by Laird, Quinn, and Hulett have also been discussed by Baxter and Hartmann. To these criticisms Hulett and Quinn [1] have replied, showing that certain supposed errors in their work were avoided, and that the criticisms were, in their opinion, unsound. At present the questions at issue between the two groups of chemists seem to be not wholly settled, and for that reason I prefer to adopt, at least provisionally, the mean value

$$Cd = 112.376 \pm .0005;$$

rejecting the very low determinations which are surely wrong. This value, moreover, includes and approximates to the excellent determinations of Morse and Arbuckle, which should not be wholly disregarded.

MERCURY.

In dealing with the atomic weight of mercury we may reject the early determinations by Sefström [2] and a large part of the work done by Turner.[3] The latter chemist, in addition to the data which will be cited below, gives figures to represent the percentage composition of both the chlorides of mercury; but these results are neither trustworthy nor in proper shape to be used.

First in order we may consider the percentage composition of mercuric oxide, as established by Turner and by Erdmann and Marchand. In both investigations the oxide was decomposed by heat, and the mercury was accurately weighed. Gold leaf served to collect the last traces of mercurial vapor.

Turner gives four determinations. Two represent oxide obtained by the ignition of the nitrate, and two are from commercial oxide. In the first two the oxide still contained traces of nitrate, but hardly in weighable proportions. A comparison of the figures from this source with the others is sufficiently conclusive on this point. The third column represents the percentage of mercury in HgO:

144.805 grains Hg	= 11.54 grains O.	92.619 per cent.
125.980 "	10.08 "	92.592 "
173.561 "	13.82 "	92.625 "
114.294 "	9.101 "	92.620 "
		Mean, 92.614 ± .0050

Hence, Hg = 200.626.

In the experiments of Erdmann and Marchand [4] every precaution was taken to ensure accuracy. Their weighings, reduced to a vacuum, give the subjoined percentages:

HgO.	*Hg.*	*Per cent.*
82.0079	75.9347	92.594
51.0320	47.2538	92.597
84.4996	78.2501	92.604
44.6283	41.3285	92.606
118.4066	109.6408	92.597
		Mean, 92.5996 ± .0015

Hence, Hg = 200.205.

Other determinations of the same ratio, being different in character, will be considered later.

With a view to establishing the atomic weight of sulphur, Erdmann and Marchand also made a series of analyses of mercuric sulphide. These data are now best available for discus-

[1] Journ. Amer. Chem. Soc., 37, 1997. 1915.
[2] Sefström. Berz. Lehrb., 5th ed., 3, 1215. Work done in 1812.
[3] Phil. Trans., 1833, 531–535.
[4] Journ. prakt. Chem., 31, 395. 1844.

sion under mercury. The sulphide was mixed with pure copper and ignited, mercury distilling over and copper sulphide remaining behind. Gold leaf was used to retain traces of mercurial vapor, and the weighings were reduced to a vacuum:

HgS.	*Hg.*	*Per cent Hg.*
34.3568	29.6207	86.215
24.8278	21.40295	86.206
37.2177	32.08416	86.207
80.7641	69.6372	86.223
		Mean, 86.2127±.0027

Hence, Hg = 200.504.

For the percentage of mercury in mercuric chloride we have data by Turner, Millon, Svanberg, Hardin and Easley. Turner,[1] in addition to some precipitations of mercuric chloride by silver nitrate, gives two experiments in which the compound was decomposed by pure stannous chloride, and the mercury thus set free was collected and weighed. The results were as follows:

44.782 grains Hg	=	15.90 grains Cl.	73.798 per cent.	
73.09	"	25.97	"	73.784 "
			Mean,	73.791±.005

Hence, Hg = 199.677.

Millon [2] purified mercuric chloride by solution in ether and sublimation, and then subjected it to distillation with lime. The mercury was collected as in Erdmann and Marchand's experiments. Percentages of metal as follows:

73.87	73.83
73.81	73.87
Mean,	73.845±.010

Hence, Hg = 200.236.

Svanberg,[3] following the general method of Erdmann and Marchand, made three distillations of mercuric chloride with lime, with the following results:

$HgCl_2$	*Hg.*	*Per cent.*
12.048	8.889	73.780
12.529	9.2456	73.794
12.6491	9.3363	73.810
		Mean, 73.795±.006

Hence, Hg = 199.718.

More modern determinations of the atomic weight of mercury are due to Hardin,[4] whose methods were entirely electrolytic. First, pure mercuric oxide was dissolved in dilute, aqueous potassium cyanide, and electrolyzed in a platinum dish. Six determinations are published, out of a large number, but without reduction of the weights to a vacuum. The data, with a percentage column added, are as follows:

Weight HgO.	*Weight Hg.*	*Per cent Hg.*
0.26223	0.24281	92.594
.23830	.22065	92.593
.23200	.21482	92.595
.14148	.13100	92.593
.29799	.27592	92.594
.19631	.18177	92.593
		Mean, 92.594±.0003

Hence, Hg = 200.041.

Various sources of error were detected in these experiments, and the series is therefore rejected by Hardin.

Hardin also studied mercuric chloride, bromide and cyanide, and the direct ratio between mercury and silver, with reduction of weights to a vacuum. Electrolysis was conducted in a platinum dish, as usual. With the chloride and bromide, the solutions were mixed with dilute

[1] Phil. Trans., 1833, 531-535.
[2] Ann. Chim. Phys. (3), 18, 345. 1846.
[3] Journ. Prkt. Chem. 45, 472. 1848.
[4] Journ. Amer. Chem. Soc., 18, 1003. 1896.

potassium cyanide. The data for the chloride are as follows, the percentage column being added by myself.

Weight $HgCld_2$.	*Weight Hg.*	*Per cent Hg.*
0.45932	0.33912	73.831
.54735	.40415	73.838
.56002	.41348	73.833
.63586	.46941	73.823
.64365	.47521	73.831
.73281	.54101	73.827
.86467	.63840	73.832
1.06776	.78825	73.823
1.07945	.79685	73.820
1.51402	1.11780	73.830
		Mean, 73.829±.0012

Hence, Hg=200.070.

For the bromide Hardin's data are—

Weight $HgBr_2$.	*Weight Hg.*	*Per cent Hg.*
0.70002	0.38892	55.558
.56430	.31350	55.555
.57142	.31750	55.563
.77285	.42932	55.550
.80930	.44955	55.548
.85342	.47416	55.560
1.11076	.61708	55.555
1.17270	.65145	55.551
1.26186	.70107	55.559
1.40142	.77870	55.565
		Mean, 55.556±.0012

Hence, Hg=199.811.

And for the cyanide—

Weight HgC_2N_2.	*Weight Hg.*	*Per cent Hg.*
0.55776	0.44252	79.337
.63290	.50215	73.341
.70652	.56053	79.337
.80241	.63663	79.340
.65706	.52130	79.338
.81678	.64805	79.342
1.07628	.85392	79.340
1.22615	.97282	79.339
1.66225	1.31880	79.338
2.11170	1.67541	79.339
		Mean, 79.339±.0004

Hence, Hg=199.763.

In the last series cited no potassium cyanide was used, but the solution of mercuric cyanide, with the addition of one drop of sulphuric acid, was electrolyzed directly.

The direct ratio between silver and mercury was determined by throwing down the two metals, simultaneously, in the same electric current. Both metals were taken in double cyanide solution. With Hardin's equivalent weights I give a third column, showing the quantity of mercury corresponding to 100 parts of silver. Many experiments were rejected, and only the following seven are published by the author:

Weight Hg.	*Weight Ag.*	*Ratio.*
0.06126	0.06610	92.678
.06190	.06680	92.665
.07814	.08432	92.671
.10361	.11181	92.666
.15201	.16402	92.678
.26806	.28940	92.626
.82808	.89388	92.639
		Mean, 92.660±.0051

Hence, Hg=199.923.

The determinations by Easley [1] are quite unlike those made by his predecessors. First, mercuric chloride in solution was reduced to metal by means of hydrogen dioxide, and was precipitated partly as a globule and partly in finely divided form. The globule was washed with water and acetone and weighed. The finely divided mercury was again dissolved, and with a little mercury remaining in solution, was deposited electrolytically upon a gold cathode. Its weight was then added to that of the globule. The following results, with vacuum weights, were obtained:

$HgCld_2$.	*Hg.*	*Per cent Hg.*
23. 43239	17. 30826	73. 865
12. 59751	9. 30608	73. 873
10. 94042	8. 08154	73. 869
11. 73734	8. 67044	73. 871
		Mean, 73. 8695±.0012

Hence, Hg = 200.490.

In the filtrate from the mercury the chlorine was precipitated as silver chloride and so weighed. The results were as follows, with vacuum weights:

$HgCl_2$.	*AgCl.*	*Ratio.*
10. 50276	11. 08744	94. 7257
9. 03634	9. 54027	94. 7179
23. 43239	24. 73606	94. 7297
10. 94042	11. 55158	94. 7093
11. 11409	11. 73470	94. 7113
16. 63910	17. 56808	94. 7121
		Mean, 94. 7177±.0023

Hence, Hg = 200.617.

In a second memoir Easley [2] gives two series of electrolytic analyses of mercuric chloride, with elaborate precautions to insure accuracy, including, of course, the reduction of his weights to a vacuum. The data are as follows:

Preliminary series.

$HgCl_2$.	*Hg.*	*Per cent Hg.*
10. 05743	7. 43123	73. 888
8. 41289	6. 21687	73. 897
10. 99056	8. 11897	73. 873
10. 28282	7. 59681	73. 879
19. 57120	14. 46032	73. 886
		Mean, 73. 885±. 0027

Hence, Hg = 200. 651.

Final series.

$HgCl_2$.	*Hg.*	*Per cent Hg.*
8. 14695	6. 01909	73. 882
11. 03181	8. 15592	73. 884
13. 48192	9. 96129	73. 886
11. 08026	8. 18610	73. 880
11. 31231	8. 35819	73. 886
21. 44026	15. 84060	73. 882
		Mean, 73. 883±. 0008

Hence, Hg = 200. 630.

Combining these series with the earlier determinations of the ratio we have:

Turner	73. 791 ±. 0050
Millon	73. 845 ±. 0100
Svanberg	73. 795 ±. 0060
Hardin	73. 839 ±. 0012
Easley, first	73. 8695±. 0012
Easley, second	73. 885 ±. 0027
Easley, third	73. 883 ±. 0008
General mean	73. 870 ±. 0007

[1] Journ. Amer. Chem. Soc., 31, 1207. 1909.

[2] Journ. Amer. Chem. Soc., 32, 1117. 1910.

In a still later investigation Easley and Brann [1] made analyses of mercuric bromide. Their data, with vacuum weights, give the ratio $2AgBr : HgBr_2 :: 100 : x$, as follows:

$HgBr_2$.	*AgBr.*	*Ratio.*
8. 93958	9. 31480	95. 972
14. 36691	14. 96940	95. 975
10. 13638	10. 56230	95. 972
9. 94452	10. 36218	95. 969
12. 60142	13. 13051	95. 971
12. 16157	12. 67122	95. 978
11. 19762	11. 66809	95. 968
16. 16607	16. 84235	95. 985
11. 28487	11. 75970	95. 962
17. 25074	17. 97597	95. 966
14. 20924	14. 80685	95. 964
		Mean, 95. 971±. 0013

Hence, Hg = 200. 371.

A new method was adopted by Taylor and Hulett [2] for determining the composition of mercuric oxide. The powdered oxide was heated in a sealed tube with finely divided iron, and the mercury so liberated formed a perfectly clear globule which was easily weighed. Their data, with vacuum weights, and the usual percentage follows:

HgO.	*Hg.*	*Per cent Hg.*
2. 98464	2. 76390	92. 604
3. 61841	3. 35066	92. 601
3. 82184	3. 53923	92. 606
3. 40356	3. 15185	92. 605
3. 80726	3. 52567	92. 606
3. 56858	4. 23065	92. 603
5. 42945	5. 02819	92. 609
2. 38313	2. 20681	92. 602
3. 76766	3. 48933	92. 612
		Mean, 92. 6053±. 0008

Hence, Hg = 200.371.

Combining this series with its predecessors we have:

Turner	92. 614 ±. 0050
Erdmann and Marchand	92. 5996±. 0015
Hardin	92. 594 ±. 0003
Taylor and Hulett	92. 6053±. 0008
General mean	92. 5952±. 00028

The determination of the atomic weight of mercury by Baker and Watson [3] appeared in 1913. They effected the synthesis of mercuric bromide by the direct union of mercury and bromine. With vacuum weights and the usual percentage column the data are as follows:

Hg.	*Br.*	*Per cent Hg in $HgBr_2$.*
4. 88190	3. 89084	55. 649
6. 74796	5. 37850	55. 648
4. 79430	3. 82210	55. 642
4. 52480	3. 60568	55. 652
4. 78892	3. 81642	55. 651
5. 52880	4. 40526	55. 655
4. 40148	3. 50738	55. 652
4. 52338	3. 60456	55. 652
5. 44704	4. 33980	55. 657
		Mean, 55. 651±. 0010

[1] Journ. Amer. Chem. Soc., 34, 137. 1912. [2] Journ. Phys. Chem., 17, 755. 1913. [3] Journ. Chem. Soc., 105, 2530. 1913.

For the same ratio Hardin's analyses gave $55.556 \pm .0012$ per cent. The two series combined give $55.612 \pm .0008$. From Baker and Watson's series alone, Hg = 200.581.

The following ratios are now available for computing the atomic weight of mercury:

(1) $HgO : Hg :: 100 : 92.5952 \pm .00028$.
(2) $HgS : Hg :: 100 : 86.2127 \pm .0027$.
(3) $HgCl_2 : Hg :: 100 : 73.870 \pm .0007$.
(4) $HgBr_2 : Hg :: 100 : 55.612 \pm .0008$.
(5) $HgC_2N_2 : Hg :: 100 : 79.339 \pm .0004$.
(6) $2Ag : Hg :: 100 : 92.660 \pm .0051$.
(7) $2AgCl : HgCl_2 :: 100 : 94.7177 \pm .0023$.
(8) $2AgBr : HgBr_2 :: 100 : 95.971 \pm .0013$.

The antecedent atomic weights are—

Ag = 107.880 ± .00016	S = 32.065 ± .00012
Cl = 35.4605 ± .00011	N = 14.0081 ± .00008
Br = 79.9228 ± .00015	C = 12.0025 ± .00019

Hence,

From ratio—	
5	Hg = 199.763 ± .0048
6	199.923 ± .0110
1	200.076 ± .0076
4	200.264 ± .0046
3	200.495 ± .0057
2	200.504 ± .0399
7	200.617 ± .0067
8	200.627 ± .0049
General mean	Hg = 200.277 ± .0022

This combination is by no means satisfactory. Mathematically, Hardin's determinations outweigh all the others, a superiority to which they are not entitled. If we reject the two lowest values in the combination, the others give a general value of Hg = 200.432; a value which seems to be much nearer the truth. If we reject all determinations of the atomic weight of mercury made before 1900, and use only those by Easley, Easley and Brann, Taylor and Hulett, and Baker and Watson, we may be on safer ground. These determinations are as follows:

Easley, analyses of $HgCl_2$	Hg = 200.589 ± .0053
Easley, ratio $2AgCl : HgCl_2$	200.617 ± .0067
Easley and Brann, ratio $2AgBr : HgBr_2$	200.627 ± .0049
Taylor and Hulett, analyses of HgO	200.371 ± .0217
Baker and Watson, syntheses of $HgBr_2$	200.581 ± .0058
General mean	Hg = 200.600 ± .0028

This value seems to be the most probable one for the atomic weight of mercury, and it is exactly that which appears in the latest reports of the International Committee on Atomic Weights. The value thus found, however, cannot be regarded as final. The analyses of mercuric oxide by Taylor and Hulett give a much lower value, and their mode of operation appears to be sound. The discrepancy, which is like that noticed under cadmium, is unexplained.

BORON.

In the first edition of this book the data relative to boron were few and unimportant. There was a little work on record by Berzelius and by Laurent, and this was eked out by a discussion of Deville's analyses of boron chloride and bromide. As the latter were not intended for atomic weight determinations they will be omitted from the present recalculation, which includes a number of later researches.

Berzelius [1] based his determination upon three concordant estimations of the percentage of water in borax. Laurent [2] made use of two similar estimations, and all five may be properly put in one series, thus:

47.10	Berzelius
47.10	Berzelius
47.10	Berzelius
47.15	Laurent
47.20	Laurent

Mean, 47.13±.013

Hence, B = 11.023.

In 1869 Dobrovolsky [3] published a dissertation, in Russian, on the atomic weight of boron. The original I have not seen, and I am therefore compelled to use the data as cited by Brauner.[4] According to Dobrovolsky, borax is completely dehydrated by ignition when small quantities of it are taken. With large quantities, some water is retained. Two series of experiments are given to illustrate this assertion:

First series.

Borax.	*Water.*	*Per cent water.*
0.138	0.0651	47.174
.283	.1338	47.279
.312	.1472	47.179
		Mean, 47.211±.023

Hence, B = 10.859.

Second series.

Borax.	*Water.*	*Per cent water.*
2.701	1.268	46.946
1.793	.843	47.016
3.004	1.402	46.671
		Mean, 46.878±.072

Hence, B = 11.529.

In 1892 the posthumous notes of Hoskyns-Abrahall were edited and published by Ewan and Hartog.[5] This chemist especially studied the ratio between boron bromide and silver, and also redetermined the percentage of water in crystallized borax. The latter work, which was purely preliminary, although carried out with great care, gave the following results, reduced to a vacuum:

$Na_2B_4O_7.10H_2O$.	$Na_2B_4O_7$.	*Per cent* H_2O.
7.00667	3.69587	47.2069
12.95936	6.82560	47.3308
4.65812	2.45248	47.3504
4.47208	3.93956	47.2763
4.94504	2.60759	47.2686
		Mean, 47.2866±.0171

Hence, B = 10.703.

Two sets of determinations were made with the bromide, which was prepared from boron and bromine directly, freed from excess of the latter by standing over mercury, and finally collected, after distillation, in small, weighed, glass bulbs. It was titrated with a solution of silver after all the usual precautions. The first series of experiments was as follows, with BBr_3 proportional to 100 parts of silver stated as the ratio:

BBr_3.	*Ag.*	*Ratio.*
1.31203	1.69406	77.449
4.39944	5.67829	77.478
5.04022	6.50820	77.444
6.51597	8.38919	77.433
7.75343	10.01235	77.439
		Mean, 77.449±.0053

[1] Poggend. Annal., 8, 1. 1826.
[2] Journ. prakt. Chem., 47, 415. 1849.
[3] Doctoral Dissertation, Kiev, 1869.
[4] In Abegg's Handbuch der anorganischen Chemie, Bd. 3, Abth. 1, p. 6.
[5] Journ. Chem. Soc., 61, 650. 1892.

This series of data is regarded by the editors as preliminary, and not entitled to much consideration. The second series, which follows, was the final one; both represent vacuum standards:

BBr_3.	Ag.	Ratio.
4.467835	5.771268	77.415
8.423151	10.880648	77.414
1.655111	2.137593	77.429
8.032352	10.374201	77.426
4.092743	5.285949	77.427
2.389993	3.086842	77.425
7.721944	9.974054	77.420
		Mean, 77.422±.0018
		First series, 77.449±.0053
		General mean, 77.425±.0017

Hence, B = 10.800.

Ramsay and Aston,[1] in their paper upon the atomic weight of boron, suggest that Abrahall's bromide may have contained hydrobromic acid, which would fully account for the low result obtained. They themselves adopt two distinct methods, the first one being the time-honored determination of water in crystallized borax. The latter was prepared from pure boric acid and pure sodium hydroxide. Results as follows, reduced to a vacuum :

$Na_2B_4O_7.10H_2O$.	$Na_2B_4O_7$.	Per cent. H_2O.
10.3581602	5.4784357	47.1099
5.3440080	2.8246677	47.1433
4.9962580	2.6378934	47.2026
5.7000256	3.0101127	47.1912
5.3132725	2.8065646	47.1882
4.9971924	2.6392016	47.1865
5.2366921	2.7674672	47.1524
		Mean, 47.1677±.0086

Hence, B = 10.946.

The second method adopted by Ramsay and Aston was to distill anhydrous borax with hydrochloric acid and methyl alcohol, both scrupulously pure, thereby converting it into sodium chloride. The operation was conducted in a glass flask, and in the first series of determinations ordinary soft glass was used. This, however, was somewhat attacked, so that the sodium chloride contained silica; hence oxygen in the material of the flask had been replaced by chlorine, thereby increasing its weight and lowering the apparent atomic weight of boron. It a second series flasks of hard combustion tubing were taken, and the error, though not absolutely avoided, was reduced to a very small amount. Both series are subjoined, together with the percentage of chloride formed; but the weights, given by the authors to seven decimal places, are only quoted to the nearest tenth milligramme. They are reduced to a vacuum:

First Series.

$Na_2B_4O_7$.	NaCl.	Per cent NaCl.
4.7684	2.7598	57.877
5.2740	3.0578	57.978
3.2344	1.8727	57.899
4.0862	2.3713	58.032
3.4970	2.0266	57.953
		Mean, 57.948±.0187

Second Series.

$Na_2B_4O_7$.	NaCl.	Per cent NaCl.
5.3118	3.0761	57.911
4.7806	2.7700	57.943
4.9907	2.8930	57.968
4.7231	2.7360	57.928
3.3138	1.9187	57.900
		Mean, 57.930±.0081
		First series, 57.948±.0187
		General mean of both, 57.933±.0074

Hence, B = 10.955.

[1] Journ. Chem. Soc., 63, 211. 1893.

As a check upon the last series of results, the sodium chloride was dissolved in water, and precipitated with silver nitrate. The silver chloride was collected and weighed in a Gooch crucible, and its weight gives a new ratio with anhydrous borax. The cross ratio between the two chlorides, silver and sodium, has already been used in the discussion upon sodium. The new ratio I give in terms of $Na_2B_4O_7$ equivalent to 100 parts of AgCl.

$Na_2B_4O_7$.	*AgCl.*	*Ratio.*
5.3118	7.5259	70.580
4.7806	6.7794	70.517
4.9907	7.0801	70.489
4.7231	6.6960	70.536
3.3138	4.6931	70.610
		Mean, 70.546±.0146

Hence, B = 11.059.

Rimbach [1] based his determination of the atomic weight of boron upon the fact that boric acid is neutral to methyl orange, and that therefore it is possible to titrate a solution of borax directly with hydrochloric acid. His borax was prepared from carefully purified boric acid and sodium carbonate, and his hydrochloric acid was standardized by a series of precipitations and weighings as silver chloride. It contained 1.84983 per cent of actual HCl. The borax, dissolved in water, was titrated by means of a weight-burette. I give the weights found in the first and second columns of the following table, and in the third column, calculated by myself, the HCl proportional to 100 parts of crystallized borax. Rimbach himself computes the percentage of Na_2O and thence the atomic weight of boron, but the ratio $Na_2B_4O_7.10H_2O$: 2HCl is the ratio actually determined.

$Na_2B_4O_7.10H_2O$.	*HCl Solution.*	*Ratio.*
10.00214	103.1951	19.0853
15.32772	158.1503	19.0864
15.08870	155.7271	19.0917
10.12930	104.5448	19.0922
5.25732	54.2571	19.0908
15.04324	155.2307	19.0883
15.04761	155.2959	19.0908
10.43409	107.6602	19.0868
5.04713	52.0897	19.0915
		Mean, 19.0893±.0006

Hence, B = 11.006.

Obviously, this error should be increased by the probable errors involved in standardizing the acid, but they are too small to be worth considering.

The work of Armitage on the atomic weight of boron was published only in abstract.[2] The data, however, were fortunately given to Brauner,[3] who stated them in partially available form. First, six determinations were made of the proportion of water in borax giving in mean, 47.1475 per cent with a minimum of 47.1224 and a maximum of 47.1637. Hence, B = 10.986. If these figures alone are considered, the probable error of the mean is ±.0091. Secondly, anhydrous borax was titrated with standard sulphuric acid, with the subjoined results:

$Na_2B_4O_7$.	*SO_4.*	*Ratio.*
1.94033	.924615	209.053
1.56303	.743413	210.251
		Mean, 210.052±.133

Hence, B = 10.933. The determination is evidently of small significance.

[1] Ber. Deutsch. chem. Ges., 26, 164. 1893.

[2] Proc. Chem. Soc., 14, 22. 1898. The commnication was followed by several adverse critisms. See also Leonard, Chem. New, 77, 104.

[3] Op. cit.

Combining the data relative to the percentage of water in borax, we have—

Berzelius with Laurent	47.130 ±.0130
Dobrovolsky, 1	47.211 ±.0230
Dobrovolsky, 2	46.878 ±.0720
Hoskyns-Abrahall	47.2866±.0171
Ramsay and Aston	47.1677±.0086
Armitage	47.1475±.0091
General mean	47.1654±.0052

This mean is very close to that of Ramsay and Aston. Dobrovolsky's figures count for practically nothing.

Gautier's determinations[1] were based upon analyses of four boron compounds. First, boron sulphide was decomposed by caustic soda; the solution was then oxidized with bromine water, and the sulphur was precipitated and weighed as barium sulphate. I give the ratio $3BaSO_4 : B_2S_3 :: 100 : x$ in the third column below. The weights are all reduced to a vacuum.

B_2S_3.	*$BaSO_4$.*	*Ratio.*
0.2754	1.6312	16.883
.3380	2.0004	16.897
.3088	1.8300	16.874
.2637	1.5614	16.888
		Mean, 16.8855±.0033

Hence, B = 11.024.

Secondly, boron carbide was heated in chlorine to expel the boron as BCl_3. The residual carbon was then burned in oxygen, and the dioxide so produced was weighed. I subjoin the weights, and also the ratio $CO_2 : B_6C :: 100 : x$:

B_6C.	*CO_2.*	*Ratio.*
0.2686	0.1515	177.293
.3268	.1844	177.224
		Mean, 177.258±.024

Hence, B = 10.997.

Third, boron tribromide was decomposed by water, and its bromine content was then determined as silver bromide. The following data relate to two samples of the boron compound, with five analyses of the first lot and four of the second:

BBr_3.	*AgBr.*	*Ratio.*
3.1130	6.994	44.510
3.3334	7.490	44.505
3.7456	8.414	44.516
3.2780	7.364	44.514
4.2074	9.452	44.513
3.3956	7.628	44.515
4.0295	9.052	44.514
3.7886	8.512	44.509
3.1711	7.124	44.513
		Mean, 44.512±.0009

Hence, B = 11.016.

Finally, the analysis of boron chloride was effected in the same way with the following results:

BCl_3.	*AgCl.*	*Ratio.*
2.6412	9.682	27.279
2.7920	10.234	27.282
2.4634	9.026	27.292
2.4489	12.640	27.285
2.2015	8.070	27.280
2.6957	9.878	27.289
		Mean, 27.2845±.0014

Hence, B = 10.947.

[1] Ann. Chim. Phys. (7), 18, 352. 1899.

The work of Gautier on boron sulphide and carbide may safely be disregarded in the final discussion. The compounds were unsuited to accurate atomic weight determinations, and the carbide was confessedly impure. The sulphate series of Armitage is also of no present value.

The determinations of the atomic weight of boron by Smith and Van Haagen[1] are entirely unlike those of their predecessors. Anhydrous borax, $Na_2B_4O_7$, was converted into the sulphate, nitrate, carbonate, chloride, and fluoride, and from the ratios so determined the required atomic weight was computed. A fundamental problem was to prepare an absolutely anhydrous tetraborate, and that was a matter of great difficulty. Failure to accomplish this result vitiated many of the previous determinations.

The conversion of the anhydrous borax into the other sodium salts involved several distinct methods. The sulphate and nitrate were formed by direct treatment of the borax with sulphuric or nitric acid, and the boric acid that was liberated was then expelled as methyl borate by distillation with methyl alcohol, a well-known process. This process was followed in all the determinations. In order to convert the borax into sodium carbonate it was dissolved in a little water and then evaporated to dryness in a current of carbon dioxide. The residue was then repeatedly evaporated with methyl alcohol in a steady stream of carbon dioxide. The entire cycle of operations was repeated twice, and the sodium carbonate, entirely free from boric acid, was finally fused in an atmosphere of carbon dioxide.

The transformation of the sodium tetraborate into chloride or fluoride was effected by a preliminary conversion into formate by means of formic acid, and a subsequent treatment with hydrochloric or hydrofluoric acid. With one exception the chloride or fluoride thus obtained was, after weighing, treated with sulphuric acid and converted into sulphate, giving additional, although somewhat indirect, values for the borate-sulphate ratio. For the elaborate details of all these operations and the great care taken to eliminate sources of error, the original memoir should be consulted. The data obtained, rearranged in order to fit the system adopted in this work, are as follows. The weights were all reduced to a vacuum.

Ratio $Na_2SO_4 : Na_2B_4O_7 :: 100 : x$.

Na_2SO_4.	$Na_2B_4O_7$.	*Ratio.*
0.63313	0.89853	141.919
.49113	.69695	141.907
1.12315	1.59374	141.899
1.12889	1.60201	141.910
1.86597	2.64768	141.893
		Mean, 141.906±.0030

Hence, B = 10.904.

Ratio $2NaF : Na_2B_4O_7 :: 100 : x$.

NaF.	$Na_2B_4O_7$.	*Ratio.*
0.29042	0.69695	239.988
.83003	1.99197	239.988
.66757	1.60201	239.976
1.10329	2.64768	239.980
		Mean, 239.983±.0020

Hence, B = 10.903, when F = 19.0045; a value derived from the ratio between NaF and Na_2SO_4, as deduced from Smith and Van Haagen's ratios.

Ratio $Na_2CO_3 : Na_2B_4O_7 :: 100 : x$.

Na_2CO_3.	$Na_2B_4O_7$.	*Ratio.*
1.03946	1.97702	190.197

Hence, B = 10.905.

Ratio $2NaNO_3 : Na_2B_4O_7 :: 100 : x$.

$NaNO_3$.	$Na_2B_4O_7$.	*Ratio.*
1.57250	1.86458	118.574

[1] Publ. No. 267, Carnegie Inst. Washington. 1918.

Hence, B = 10.899.

Ratio 2NaCl : $Na_2B_4O_7$: : 100 : x.

NaCl.	*$Na_2B_4O_7$.*	*Ratio.*
0.52112	0.89853	172.423

Hence, B = 10.901.

For this ratio inverted, that is for the percentage of NaCl yielded by $Na_2B_4O_7$, Ramsay and Aston found the value 57.933 ± .0074, While Smith and Van Haagen's value becomes 57.997. Assigning this equal weight with the other the general mean of the two is 57.965 ± .0052. The Ramsay and Aston value might be rejected entirely, for their boron was probably not absolutely anhydrous; but as this study is in part one of the compensation of errors it may be allowed to stand provisionally.

The ratios from which to compute the atomic weight of boron are now as follows:

(1) $Na_2B_4O_7.10H_2O : 10H_2O :: 100 : 47.1654 \pm .0052$.
(2) $Na_2B_4O_7.10H_2O : 2HCl :: 100 : 19.0893 - .0006$.
(3) $Na_2B_4O_7 : 2NaCl :: 100 : 57.965 \pm .0052$.
(4) $2AgCl : Na_2B_4O_7 :: 100 : 70.546 \pm .0146$.
(5) $2NaF : Na_2B_4O_7 :: 100 : 239.983 \pm .0020$.
(6) $2NaNO_3 : Na_2B_4O_7 :: 100 : 118.574 \pm .0070$.
(7) $Na_2CO_3 : Na_2B_4O_7 :: 100 : 190.197 \pm .0070$.
(8) $Na_2SO_4 : Na_2B_4O_7 :: 100 : 141.906 \pm .0030$.
(9) $3AgCl : BCl_3 :: 100 : 27.2845 \pm .0014$.
(10) $3Ag : BBr_3 :: 100 : 77.425 \pm .0017$.
(11) $3AgBr : BBr_3 :: 100 : 44.512 \pm .0009$.

The probable errors assigned to ratios 6 and 7 are in each case that of a single determination in Smith and Van Haagen's sulphate series.

The values used in reducing these ratios are:

Ag = 107.880 ± .00016	Na = 23.0029 ± .00012
Cl = 35.4605 ± .00011	N = 14.0081 ± .00008
Br = 79.9228 ± .00015	C = 12.0025 ± .00019
F = 19.0045 ± .0012	H = 1.0078 ± .00001

Hence,

From ratio—	
10	B = 10.800 ± .0056
6	10.899 ± .0037
5	10.903 ± .0015
8	10.904 ± .0011
7	10.905 ± .0018
3	10.929 ± .0050
9	10.947 ± .0061
1	10.951 ± .0074
2	11.006 ± .0031
11	11.016 ± .0051
4	11.059 ± .0105
General mean	B = 10.912 ± .0007

In this combination the determinations by Smith and Van Haagen outweigh all the others. At the end of their memoir they give a careful discussion of all the other data, and point out probable sources of error in the methods previously employed. Their final value, B = 10.900, appears to be very near the truth, and it may reasonably be adopted for general use.

ALUMINUM.

The atomic weight of aluminum has been determined by Berzelius, Mather, Tissier, Dumas, Isnard, Terreil, Mallet, Baubigny, Thomsen, and Kohn-Abrest. The early calculations of Davy and of Thomson we may properly disregard.

Berzelius'[1] determination rests upon a single experiment. He ignited 10 grammes of dry aluminum sulphate, $Al_2(SO_4)_3$, and obtained 2.9934 grammes of Al_2O_3 as residue.

Hence Al = 27.30.

In 1835 Mather[2] published a single analysis of aluminum chloride, from which he sought to fix the atomic weight of the metal. 0.646 grams of $AlCl_3$ gave him 2.056 of AgCl and 0.2975 of Al_2O_3. These figures give worthless values for Al, and are included here only for the sake of completeness. From the ratio between AgCl and $AlCl_3$, Al = 28.731.

Tissier's[3] determination, also resting on a single experiment, appeared in 1858. Metallic aluminum, containing 0.135 per cent of sodium, was dissolved in hydrochloric acid. The solution was evaporated with nitric acid to expel all chlorine, and the residue was strongly ignited until only alumina remained. 1.935 grammes of Al gave 3.645 grammes of Al_2O_3. If we correct for the trace of sodium in the aluminum, we have Al = 27.185.

Essentially the same method of determination was adopted by Isnard,[4] who, although not next in chronological order, may fittingly be mentioned here. He found that 9 grammes of aluminum gave 17 grammes of Al_2O_3. Hence Al = 27.

In 1858 Dumas,[5] in his celebrated revision of the atomic weights, made seven experiments with aluminum chloride. The material was prepared in quantity, sublimed over iron filings, and finally resublimed from metallic aluminum. Each sample used was collected in a small glass tube, after sublimation from aluminum in a stream of dry hydrogen, and hermetically inclosed. Having been weighed in the tube, it was dissolved in water, and the quantity of silver necessary for precipitating the chlorine was determined. Reducing to a common standard, his weighings give the quantities of $AlCl_3$ stated in the third column, as proportional to 100 parts of silver:

$AlCl_3$.	*Ag.*	*Ratio.*
1. 8786	4. 543	41. 352
3. 021	7. 292	41. 459—Bad
2. 399	5. 802	41. 348
1. 922	4. 6525	41. 311
1. 697	4. 1015	41. 375
4. 3165	10. 448	41. 314
6. 728	16. 265	41. 365

In the second experiment the $AlCl_3$ contained traces of iron. Rejecting this experiment, the remaining six give a mean of $41.344 \pm .007$. These data give a value for Al approximating to 27.4, and were for many years regarded as satisfactory. It now seems probable that the chloride contained traces of an oxy-compound, which would tend to raise the atomic weight.

In 1879 Terreil[6] published a new determination of the atomic weight under consideration, based upon a direct comparison of the metal with hydrogen. Metallic aluminum, contained in a tube of hard glass, was heated strongly in a current of dry hydrochloric acid. Hydrogen was set free, and was collected over a strong solution of caustic potash. 0.410 gramme of aluminum thus was found equivalent to 508.2 cubic centimeters, or 0.045671 gramme of hydrogen. Hence, Al = 27.142.

About a year after Terreil's determination appeared, the lower value for aluminum was thoroughly confirmed by J. W. Mallet.[7] After giving a full résumé of the work done by others, exclusive of Isnard, the author describes his own experiments, which may be summarized as follows:

Four methods of determination were employed, each one simple and direct, and at the same time independent of the others. First, pure ammonia alum was calcined, and the residue of aluminum oxide was estimated. Second, aluminum bromide was titrated with a standard solution of silver. Third, metallic aluminum was attacked by caustic soda, and the hydrogen evolved was measured. Fourth, hydrogen was set free by aluminum, and weighed as water. Every weight was carefully verified, the verification being based upon the direct comparison, by J. E. Hilgard, of a kilogramme weight with the standard kilogramme at Washington. The

[1] Poggend. Annal., 8, 177.
[2] Amer. Journ. Sci., 27, 241.
[3] Compt. Rend., 46, 1105.
[4] Compt. Rend., 66, 508. 1868.
[5] Ann. Chim. Phys. (3), 55, 151. Ann. Chem. Pharm., 113, 26.
[6] Bull. Soc. Chim., 31, 153.
[7] Phil. Trans., 1880, p. 1003.

specific gravity of each piece was determined, and also of all materials and vessels used in the weighings. During each weighing both barometer and thermometer were observed, so that every result represents a real weight in vacuo.

The ammonium alum used in the first series of experiments was specially prepared, and was absolutely free from ascertainable impurities. The salt was found, however, to lose traces of water at ordinary temperatures—a circumstance which tended toward a slight elevation of the apparent atomic weight of aluminum as calculated from the weighings. Two sets of experiments were made with the alum; one upon a sample air-dried for two hours at 21°-25°, the other upon material dried for twenty-four hours at 19°-26°. These sets, marked A and B, respectively, differ slightly, B being the less trustworthy of the two, judged from a chemical standpoint. Mathematically, it is the better of the two. Calcination was effected with a great variety of precautions, concerning which the original memoir must be consulted. To Mallet's weighings I append the percentages of Al_2O_3 deduced from them:

Series A.

Alum.	*Al_2O_3.*	*Per cent.*
8.2144	.9258	11.270
14.0378	1.5825	11.273
5.6201	.6337	11.275
11.2227	1.2657	11.278
10.8435	1.2216	11.266
		Mean, 11.2724±.0014

Series B.

Alum.	*Al_2O_3.*	*Per cent.*
12.1023	1.3660	11.287
10.4544	1.1796	11.283
6.7962	.7670	11.286
8.5601	.9654	11.278
4.8992	.5528	11.283
		Mean, 11.2834±.0011

Combined, these series give a general mean of 11.2793±.0008. Hence, Al=27.153.

The aluminum bromide used in the second series of experiments was prepared by the direct action of bromine upon the metal. The product was repeatedly distilled, the earlier portions of each distillate being rejected, until a constant boiling point of 263.3° at 747 mm. pressure was noted. The last distillation was effected in an atmosphere of pure nitrogen, in order to avoid the possible formation of oxide or oxybromide of aluminum; and the distillate was collected in three portions, which proved to be sensibly identical. The individual samples of bromide were collected in thin glass tubes, which were hermetically sealed after nearly filling. For the titration pure silver was prepared, and after fusion upon charcoal it was heated in a Sprengel vacuum in order to eliminate occluded gases. This silver was dissolved in specially purified nitric acid, the latter but very slightly in excess. The aluminum bromide, weighed in the sealed tube, was dissolved in water, precautions being taken to avoid any loss by splashing or fuming which might result from the violence of the action. To the solution thus obtained the silver solution was added, the silver being something less than a decigramme in deficiency. The remaining amount of silver needed to complete the precipitation of the bromine was added from a burette, in the form of a standard solution containing one milligramme of metal to each cubic centimetre. The final results were as follows, the figures in the third column representing the quantities of bromide proportional to 100 parts of silver. Series A is from the first portion of the last distillate of $AlBr_3$; series B from the second portion, and series C from the third portion:

Series A.

$AlBr_3$.	*Ag.*	*Ratio.*
6.0024	7.2793	82.458
8.6492	10.4897	82.454
3.1808	3.8573	82.462

Series B.

$AlBr_3$.	*Ag.*	*Ratio.*
6.9617	8.4429	82.456
11.2041	13.5897	82.445
3.7621	4.5624	82.459
5.2842	6.4085	82.456
9.7338	11.8047	82.457

Series C.

$AlBr_3$.	*Ag.*	*Ratio.*
9.3515	11.3424	82.447
4.4426	5.3877	82.458
5.2750	6.3975	82.454
		Mean, $\overline{82.455} \pm .001$

Hence, Al = 27.089.

The experiments to determine the amount of hydrogen evolved by the action of caustic soda upon metallic aluminum were conducted with pure metal, specially prepared, and with caustic soda made from sodium. The soda solution was so strong as to scarcely lose a perceptible amount of water by the passage through it of a dry gas at ordinary temperature. As the details of the experiments are somewhat complex, the original memoir must be consulted for them. The following results were obtained, the weight of the hydrogen being calculated from the volume, reckoned at .089872 gramme per liter:

Wt. Al.	*Vol. H.*	*Wt. H.*	*At. Wt. (H=1).*
0.3697	458.8	0.041234	26.898
.3769	467.9	.042051	26.889
.3620	449.1	.040362	26.907
.7579	941.5	.084614	26.872
.7314	907.9	.081595	26.891
.7541	936.4	.084156	26.882
			Mean, $\overline{26.890} \pm .0034$

Hence, Al = 27.099, when O = 16.

The closing series of experiments was made with larger quantities of aluminum than were used in the foregoing set. The hydrogen, evolved by the action of the caustic alkali, was dried by passing it through two drying tubes containing pumice stone and sulphuric acid, and two others containing asbestos and phosphorus pentoxide. Thence it passed through a combustion tube containing copper oxide heated to redness. A stream of dry nitrogen was employed to sweep the last traces of hydrogen into the combustion tube, and dry air was afterwards passed through the entire apparatus to reoxidize the surface of reduced copper, and to prevent the retention of occluded hydrogen. The water formed by the oxidation of the hydrogen was collected in three drying tubes. The results obtained were as follows. The third column gives the amount of water formed from 10 grammes of aluminum:

Al.	H_2O.	*Ratio.*
2.1704	2.1661	9.9802
2.9355	2.9292	9.9785
5.2632	5.2562	9.9867
		Mean, $\overline{9.9818} \pm .0017$

Hence, Al = 27.073.

From the last two series of experiments an independent value for the atomic weight of oxygen may be calculated. They give O = 15.895, when H = 1. The closeness of this figure to some of the best determinations affords a good indication of the accuracy of Mallet's work.

In connection with Mallet's work it is worth noting that Torrey [1] published a series of measurements of the H : Al ratio, representing determinations made under his direction by elementary students. These measurements are thirteen in number, and calculated with Regnault's old value for the weight of hydrogen, range from 26.661 to 27.360, or in mean, 27.049 $\pm$.323. Corrected by the latest value for the weight of H, this mean becomes 26.967, when H = 1. This figure, of course, has only confirmatory significance.

[1] Amer. Chem. Journ., 10, 74. 1888.

By Baubigny [1] we have only two determinations, based upon the calcination of anhydrous aluminum sulphate, $Al_2(SO_4)_3$.

Sulphate.	*Al_2O_3.*	*Per cent.*
3.6745	1.0965	29.841
2.539	.7572	29.823
		Mean, $\overline{29.832} \pm .0061$

Hence, Al = 27.060.

Thomsen's [2] value for the atomic weight of aluminum was derived from his earlier work on the hydrogen-oxygen ratio. In that investigation one part of aluminum was found equivalent to $0.11190 \pm .000015$ of hydrogen, and $0.88787 \pm .000018$ of oxygen. The aluminum, however, was impure, and the first step in the new research was to determine its impurities. These were, in 1 gramme of metal, 0.00819 gramme of silicon and 0.00322 of iron. Correcting for these, and also for the change of volume in the soda solution following the solution of the metal, the equivalent values become 0.99897 grm. Al, 0.11195 grm. H, and 0.88824 grm. O. From the oxygen ratio $Al = 26.992 \pm .0011$. From the hydrogen, the ratio $H : Al :: 1 : 26.765 \pm .0036$ is derived. For the same ratio Mallet found $26.890 \pm .0034$. The two series, combined, give a general mean of $26.860 \pm .0025$.

The determinations by Kohn-Abrest [3] are of very slender value. Impure aluminum was dissolved in hydrochloric acid, the hydrogen evolved was burned over hot copper oxide, and the water formed was weighed. The weights of metal taken and the percentages of water produced are given below:

Weight Al.	*Per cent H_2O.*
0.7909	98.08
.7428	98.20
.5477	97.86
.5132	98.10
.6571	98.44
.4993	98.03
.5384	97.98
	Mean, $\overline{98.10} \pm .0473$

Corrected for the known impurities of the aluminum, this mean becomes 99.151. Hence, Al = 27.255.

Mallet's value for this ratio, reduced to the same standard, is $99.818 \pm .0170$. Combining, the general mean is $99.742 \pm .0160$.

Kohn-Abrest also made two determinations of atomic weight by converting metallic aluminum into oxide, as follows:

Al.	*Al_2O_3.*	*Per cent.*
0.3429	0.6444	53.212
.4168	.7850	53.095
		Mean, $\overline{53.153} \pm .0387$

Hence, Al = 27.230. This can be combined with Thomsen's figure for the Al : O ratio, but its probable error is so high that it exerts no appreciable influence.

It is clear that the single determinations of Berzelius, Mather, Tissier, Isnard, and Terreil may now be safely left out of account, for the reason that none of them could affect appreciably the final value for Al. The ratios to consider are as follows:

(1) $3Ag : AlCl_3 :: 100 : 41.344 \pm .0070$.
(2) Percentage Al_2O_3 in ammonium alum, $11.2793 \pm .0008$.
(3) $3Ag : AlBr_3 :: 100 : 82.455 \pm .0010$.
(4) $H : Al :: 1 : 26.860 \pm .0025$.
(5) $2Al : 3H_2O :: 100 : 99.742 \pm .0160$.
(6) $Al_2(SO_4)_3 : Al_2O_3 :: 100 : 29.832 \pm .0061$.
(7) $O : Al :: 16 : 26.992 \pm .0011$.

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[1] Compt. Rend., 97, 1369. 1883.
[2] Zeitsch. anorg. Chem., 15, 447. 1897. See also ante, p. 25.
[3] Bull. Soc. Chim. (3), 33, 121. 1905. Preliminary in Compt. Rend., 139, 669.

The antecedent atomic weights are

Ag=107.880±.00016	S=32.0650±.00012
Cl=35.4605±.00011	N=14.0081±.00008
Br=79.9228±.00015	H=1.0078 ±.00001

Hence,

From ratio—	
7	Al=26.992±.0011
6	27.060±.0055
4	27.070±.0025
3	27.089±.0014
5	27.093±.0087
2	27.153±.0037
1	27.424±.0227
General mean	Al=27.039±.0008

The last value, from ratio 1, is worthless, but is of no influence in the general combination. No one of the other values is entitled to exclusive confidence. The atomic weight of aluminum needs reinvestigation.

GALLIUM.

Gallium has been obtained in such small quantities that its atomic weight has not as yet been finally determined. The following data were fixed by the discoverer, Lecoq de Boisbaudran:[1]

3.1044 grammes gallium ammonium alum, upon ignition, left .5885 gramme Ga_2O_3.

Hence, Ga=70.12.

0.4481 gramme gallium, converted into nitrate and ignited, gave .6024 gramme Ga_2O_3.

Hence, Ga=69.70.

These values, assigned equal weight, give in mean Ga=69.91, with an uncertainty of perhaps half a unit.

Recently some preliminary determinations have been made by Richards, Craig, and Sameshima,[2] who analyzed gallium chloride by the usual Harvard method. The weights given are as follows:

$GaCl_3$.	*$NgCl$.*	*Ag.*
0.43947	1.07087	0.80587

Hence there are two values for the atomic weight of gallium, 70.09 and 70.11. The mean, 70.10, may be adopted provisionally until the more complete investigation is published.

INDIUM.

Reich and Richter, the discoverers of indium, were also the first to determine its atomic weight.[3] They dissolved weighed quantities of the metal in nitric acid, precipitated the solution with ammonia, ignited the precipitate, and ascertained its weight. Two experiments were made, as follows:

In.	*In_2O_3.*
0.5135	0.6243
.699	.8515

Hence, in mean, In=110.61; a value known now to be too low.

An unweighed quantity of fresh, moist indium sulphide was also dissolved in nitric acid, yielding, on precipitation,

0.2105 gramme In_2O_3 and 0.542 gramme $BaSO_4$.

Hence, with $BaSO_4$=233.423, In=111.99; also too low.

Soon after the publication of Reich and Richter's paper the subject was taken up by Winkler.[4] He dissolved indium in nitric acid, evaporated to dryness, ignited the residue, and weighed the oxide thus obtained.

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[1] Journ. Chem. Soc., 1878, p. 646.
[2] Proc. Nat. Acad. Sci., 4, 387. 1918.
[3] Journ. prakt. Chem., 92, 484.
[4] Journ. prakt. Chem., 94, 8.

In.	In_2O_3.
0.5574	0.6817
.6661	.8144
.5011	.6126

Hence, in mean, In = 107.76; a result even lower than the values already cited.

In a later paper by Winkler [1] better results were obtained. Two methods were employed. First, metallic indium was placed in a solution of pure, neutral, sodio-auric chloride, and the amount of gold precipitated was weighed. I give the weighings and, in a third column, the amount of indium proportional to 100 parts of gold:

In.	*Au.*	*Ratio.*
0.4471	0.8205	57.782
.8445	1.4596	57.858
		Mean, 57.820

Hence, if Au = 197.209, In = 114.03.

Winkler also repeated his earlier process, converting indium into oxide by solution in nitric acid and ignition of the residue. An additional experiment, the third as given below, was made after the method of Reich and Richter. The third column gives the percentage of In in In_2O_3:

In.	In_2O_3.	*Per cent.*
1.124	1.3616	82.550
1.015	1.2291	82.581
.6376	.7725	82.537

These figures were confirmed by a single experiment of Bunsen's,[2] published simultaneously with the specific heat determinations which showed that the oxide of indium was In_2O_3, and not InO, as has been previously supposed:

1.0592 grm. In gave 1.2825 grm. In_2O_3. 82.589 per cent.

For convenience we may add this figure in with Winkler's series, which gives a mean percentage of In in In_2O_3 of 82.564. Hence, In = 113.646.

Recent investigations have shown that all of the foregoing determinations are untrustworthy, and that they give values for the atomic weight of indium which are too low. Thiel [3] carefully investigated the properties of indium oxide, and found it to be quite unsuited to atomic weight determinations. Calcined at low temperatures it tends to retain gaseous occlusions; at high temperatures it is distinctly volatile. Syntheses of the indium halides also gave unsatisfactory results. Thiel finally made analyses of indium trichloride and tribromide, purified by sublimation, and obtained the following ratios with the corresponding silver salts. First, the ratio $3AgCl : InCl_3 : 100 : x$, with weights corrected to a vacuum:

Weight $InCl_3$.	*Weight AgCl.*	*Ratio.*
5.0194	9.7526	51.467
4.7049	9.1401	51.475
5.7067	11.0862	51.476
5.4075	10.5055	51.473
		Mean, 51.473±.0015

Hence, In = 114.96.

In the bromide series the weights were not reduced to a vacuum.

Weight $InBr_3$.	*Weight AgBr.*	*Ratio.*
8.9040	14.1531	62.912
8.2140	13.0512	62.937
9.4016	14.9422	62.920
		Mean, 62.923±.0070

Hence, In = 114.74.

Thiel regards the chloride series as the better of the two, and attaches little importance to the bromide determinations.

[1] Journ. prakt. Chem, 102, 282. [2] Poggend. Annal.,141, 28. [3] Zeitsch. anorg. Chem, 40, 280. 1904. Preliminary in Vol. 39, 119, and Ber., 37, 175.

Mathers,[1] like Thiel, derived the atomic of indium from analyses of the two trihalides. His weights and ratios are as follows:

Weight $InCl_3$.	*Weight AgCl.*	*Ratio.*
2.1156	4.11421	51.422
4.95920	9.64176	51.435
1.98175	3.85125	51.457
5.54540	10.77904	51.446
1.46361	2.84557	51.435
4.08602	7.94054	51.458
		Mean, 51.442±.0038

Hence, In = 114.83.

Combined with Thiel's series, the general mean for the ratio is 51.469±.0014.

Weight $InBr_3$.	*Weight AgBr.*	*Ratio.*
2.73494	4.34550	62.937
7.69880	12.23341	62.933
6.27450	9.96917	62.939
5.36642	8.52741	62.931
5.16112	8.20128	62.931
4.98336	7.92009	62.921
		Mean, 62.932±.0011

Hence, In = 114.83.

On combination of this series with Thiel's the general mean becomes 62.931±.0011.

Neglecting the older work there are now two ratios from which to deduce the atomic weight of indium:

(1) $3AgCl : InCl_3 :: 100 : 51.469 \pm .0014$
(2) $3AgBr : InBr_3 :: 100 : 62.932 \pm .0011$

Computing with Ag = 107.880±.00016; Cl = 35.4605±.00011; and Br = 79.9228±.00015 we have—

From ratio 2	In=114.796±.0062
From ratio 1	114.947±.0061
General mean	In=114.871±.0044

This mean is, of course, not conclusive. Other indium ratios need to be determined before the atomic weight can be more than approximately known. The true value probably lies between 114.8 and 115.0. For the present the mean value 114.8 may be accepted.

THALLIUM.

The atomic weight of this interesting metal has been fixed by the researchs of Lamy, Werther, Hebberling, Crookes, and Lepierre.

Lamy and Hebberling investigated the chloride and sulphate; Werther studied the iodide; Crookes' experiments involved the synthesis of the nitrate. Lepierre's work is still more recent and is based upon several compounds.

Lamy [2] gives the results of one analysis of thallium sulphate and three of thallium chloride. 3.423 grms. of Tl_2SO_4 gave 1.578 grm. $BaSO_4$; whence 100 parts of the latter are equivalent to 216.920 of the former.

Hence, Tl = 205.14.

In the thallium chloride the chlorine was estimated as silver chloride. The following results were obtained. In the third column I give the amount of TlCl proportional to 100 parts of AgCl:

TlCl.	*AgCl.*	*Ratio.*
3.912	2.346	166.752
3.000	1.8015	166.528
3.912	2.333	167.466
		Mean, 166.915±.1905

Hence, Tl = 203.80.

[1] Journ. Amer. Chem. Soc., 29, 485. 1907.

[2] Zeit. Anal. Chem., 2, 211. 1863.

Hebberling's [1] work resembles that of Lamy. Reducing his weighings to the standards adopted above, we have from his sulphate series, as equivalent to 100 parts of $BaSO_4$, the amounts of Tl_2SO_4 given in the third column:

Tl_2SO_4.	*$BaSO_4$.*	*Ratio.*
1.4195	0.6534	217.248
1.1924	.5507	216.524
.8560	.3957	216.325
		Mean, 216.699

Hence, Tl = 204.88.

Including Lamy's single result as of equal weight, we get a mean of 216.754 ± .1387.

From the chloride series we have these results, with the ratio stated as usual:

TlCl.	*AgCl.*	*Ratio.*
0.2984	0.1791	166.611
.5452	.3278	166.321
		Mean, 166.465 ± .097

Hence, Tl = 203.16.

Lamy's mean was 166.915 ± .1905. Both means combined give a general mean of 166.555 ± .0865.

Werther's [2] determinations of iodine in thallium iodide were made by two methods. In the first series TlI was decomposed by zinc and potassium hydroxide, and in the filtrate the iodine was estimated as AgI. One hundred parts of AgI correspond to the amounts of TlI given in the last column:

TlI.	*AgI.*	*Ratio.*
0.720	0.51	141.176
2.072	1.472	140.761
.960	.679	141.384
.385	.273	141.026
1.068	.759	140.711
		Mean, 141.012 ± .085

In the second series the thallium iodide was decomposed by ammonia in presence of silver nitrate, and the resulting AgI was weighed. Expressed according to the foregoing standard, the results are as follows:

TlI.	*AgI.*	*Ratio.*
1.375	0.978	140.593
1.540	1.095	140.639
1.380	.981	140.673
		Mean, 140.635 ± .016

General mean of both series, 140.648 ± .016. Hence Tl = 203.32.

In 1873 Crookes,[3] the discoverer of thallium, published his final determination of its atomic weight. His method was to effect the synthesis of thallium nitrate from weighed quantities of absolutely pure thallium. No precaution necessary to insure purity of materials was neglected; the balances were constructed especially for the research; the weights were accurately tested and all their errors ascertained; weighings were made partly in air and partly in vacuo, but all were reduced to *absolute* standards; and unusually large quantities of thallium were employed in each experiment. In short, no effort was spared to attain as nearly as possible absolute precision of results. The details of the investigation are too voluminous, however, to be cited here; the reader who wishes to become familiar with them must consult the original memoir.

[1] Ann. Chem. Pharm., 134, 11. 1805. [2] Journ. prakt. Chem., 92, 198. 1864. [3] Phil. Trans., 1873, p. 277.

The result of 10 experiments by Prof. Crookes may be stated as follows. In a final column I give the quantity of nitrate producible from 100 parts of thallium. The weights given are in grains:

Thallium.	*$TlNO_3$+Glass.*	*Glass Vessel.*	*Ratio.*
497.972995	1121.851852	472.557319	130.3875
293.193507	1111.387014	729.082713	130.3930
288.562777	971.214142	594.949719	130.3926
324.963740	1142.569408	718.849078	130.3900
183.790232	1005.779897	766.133831	130.3912
190.842532	997.334615	748.491271	130.3920
195.544324	1022.176679	767.203451	130.3915
201.816345	1013.480135	750.332401	130.3897
295.683523	1153.947672	768.403621	130.3908
299.203036	1159.870052	769.734201	130.3917
			Mean, 130.3910±.00034

Hence, Tl = 204.034.

Lepierre's [1] determinations were published in 1893, and represented several distinct methods. First, thallous sulphate was subjected to electrolysis in presence of an excess of ammonium oxalate, the reduced metal being dried and weighed in an atmosphere of hydrogen. The corrected weights, etc., are as follows:

Tl_2SO_4.	*Tl.*	*Per cent.*
1.8935	1.5327	80.945
2.7243	2.2055	80.957
2.8112	2.2759	80.958
		Mean, 80.953±.0030

Hence, Tl = 204.150.

Secondly, weighed quantities of crystallized thallic oxide were converted into thallous sulphate by means of sulphurous acid, and the solution was then subjected to electrolysis, as in the preceding series:

Tl_2O_3.	*Tl.*	*Per cent.*
3.2216	2.8829	89.487
2.5417	2.2742	89.475
		Mean, 89.481±.0040

Hence, Tl = 204.158.

In the third set of experiments a definite amount of thallous sulphate or nitrate was fused in a polished silver crucible with 10 times its weight of absolutely pure caustic potash. Thallic oxide was thus formed, which, with various precautions, was washed with water and alcohol, and finally weighed in the original crucible. One experiment with the nitrate gave—

2.7591 grm. $TlNO_3$ yields 2.3649 Tl_2O_3. 85.713 per cent.

Hence, Tl = 204.025.

Two experiments were made with the sulphate, as follows:

Tl_2SO_4	*Tl_2O_3.*	*Per cent.*
3.1012	2.8056	90.468
2.3478	2.1239	90.463
		Mean, 90.465±.0020

Hence, Tl = 204.012.

Finally, crystallized thallic oxide was reduced by heat in a stream of hydrogen, and the water so formed was collected and weighed.

Tl_2O_3.	*H_2O.*	*Per cent.*
2.7873	0.3301	11.843
3.9871	.4716	11.828
4.0213	.4761	11.839
		Mean, 11.837±.0029

Hence, Tl = 204.300.

[1] Bull. Soc. Chim. (3), 9, 166.

In a supplementary note[1] Lepierre states that his weights were all reduced to a vacuum standard.

Some work by Wells and Penfield,[2] incidentally involving a determination of atomic weight, but primarily intended for another purpose, may also be taken into account. Their question was as to the constancy of thallium itself. The nitrate was repeatedly crystallized, and the last crystallization, with the mother liquor representing the opposite end of the series, were both converted into chloride. In the latter the chlorine was estimated as silver chloride, which was weighed on a Gooch filter, with the results given below, which are sensibly identical. The TlCl equivalent to 100 parts of AgCl is stated in the last column.

	TlCl.	*AgCl.*	*Ratio.*
Crystals	3.9146	2.3393	167.341
Mother liquor	3.3415	1.9968	167.343
			Mean, 167.342

Hence, Tl = 204.41.

The general mean of Lamy's and Hebberling's determinations of this ratio gave 166.555 ± .0865. If we arbitrarily assign Wells and Penfield's mean equal weight with that, we get a new general mean of 166.948 ± .0610.

The ratios to be considered are now as follows:

(1) $BaSO_4 : Tl_2SO_4 :: 100 : 216.754 \pm .1387.$
(2) $AgCl : TlCl :: 100 : 166.948 \pm .0610.$
(3) $AgI : TlI :: 100 : 140.648 \pm .016.$
(4) $Tl : TlNO_3 :: 100 : 130.391 \pm .00034.$
(5) $Tl_2SO_4 : 2Tl :: 100 : 80.953 \pm .0030.$
(6) $Tl_2O_3 : 2Tl :: 100 : 89.481 \pm .0040.$
(7) $2TlNO_3 : Tl_2O_3 :: 100 : 85.713.$
(8) $Tl_2SO_4 : Tl_2O_3 :: 100 : 90.465 \pm .0020.$
(9) $Tl_2O_3 : 3H_2O :: 100 : 11.837 \pm .0029$

The antecedent atomic weights are as follows:

Ag = 107.880 ± .00016	N = 14.0081 ± .00008
Cl = 35.4605 ± .00011	S = 32.065 ± .00012
I = 126.926 ± .00023	H = 1.0078 ± .00001

Ba = 137.358 ± .0023

Ratio 7 rests upon a single experiment, and the atomic weight derived from it must therefore be arbitrarily weighted. To do this its probable error is assumed to be the same as that given by ratio 8. Taking so much for granted, the nine values for thallium are

From ratio—	
3	Tl = 203.293 ± .0376
2	203.844 ± .0875
8	204.012 ± .0696
7	204.025 ± .0695
4	204.034 ± .0035
5	204.146 ± .0330
6	204.158 ± .0780
9	204.300 ± .0593
1	204.945 ± .1619

A glance at the "probable errors" in this series of values will show that Crookes' ratio, No. 4, carries overwhelming weight. It is therefore unnecessary to compute the general mean, for it could not vary much from that. The value Tl = 204.03 is to be accepted as the best.

[1] Bull. Soc. Chim. (3), 11, 423. 1894.

[2] Amer. Journ. Sci. (3), 47, 466. 1894.

SILICON.

Although Berzelius[1] attempted to ascertain the atomic weight of silicon, first by converting pure Si into SiO_2, and later from the analysis of $BaSiFl_6$, his results were not satisfactory. We need consider only the later determinations.

Pelouze,[2] experimenting upon silicon tetrachloride, employed his usual method of titration with a solution containing a known weight of silver. One hundred parts of Ag gave the following equivalences of $SiCl_4$:

39. 4325
39. 4570

Mean, 39. 4447 ± . 0083

Hence, Si = 28.370.

Essentially the same method was adopted by Dumas.[3] Pure $SiCl_4$ was weighed in a sealed glass bulb, then decomposed by water, and titrated. The results for 100 Ag are given in the third column:

$SiCl_4$.	*Ag.*	*Ratio.*
2. 899	7. 3558	39. 411
1. 242	3. 154	39. 379
3. 221	8. 1875	39. 340
		Mean, 39. 377 ± 014

Hence, Si = 28.077.

Dumas' and Pelouze's series combine as follows:

Pelouze	39. 4447 ± . 0083
Dumas	39. 3776 ± . 014
General mean	39. 4265 ± . 0071

Schiel,[4] also studying the chloride of silicon, decomposed it by ammonia. After warming and long standing it was filtered, and in the filtrate the chlorine was estimated as AgCl. One hundred parts of AgCl correspond to the quantities of $SiCl_4$ given in the last column:

$SiCl_4$.	*AgCl.*	*Ratio.*
0. 6738	2. 277	29. 592
1. 3092	4. 418	29. 633
		Mean, 29. 6125 ± . 0138

Hence, Si = 27.945.

Thorpe and Young,[5] working with silicon bromide, obtained better results. The bromide was perfectly clear and colorless, and boiled constantly at 153°. It was weighed, decomposed with water and evaporated to dryness, the crucible containing it being finally ignited. The crucible was tared by one precisely similar, in which an equal volume of water was also evaporated. Results as follows, with vacuum weights:

$SiBr_4$.	*SiO_2.*	*Per cent.*
9. 63007	1. 67070	17. 349
12. 36099	2. 14318	17. 338
12. 98336	2. 25244	17. 349
9. 02269	1. 56542	17. 350
15. 38426	2. 66518	17. 324
9. 74550	1. 69020	17. 343
6. 19159	1. 07536	17. 368
9. 51204	1. 65065	17. 353
10. 69317	1. 85555	17. 353
		Mean, 17. 347 ± . 0027

Hence, Si = 28.381.

The determinations by Becker and Meyer [6] resemble the foregoing series, except that silicon tetrachloride was used instead of the bromide. The carefully purified substance was decomposed

[1] Lehrbuch, 5 Aufl., 3, 1200.
[2] Compt. Rend., 20, 1047. 1845.
[3] Ann. Chem. Pharm., 113, 31. 1860.
[4] Ann. Chem. Pharm., 120, 94.
[5] Journ. Chem. Soc., 51, 576. 1887.
[6] Zeitsch. anorg. Chem., 43, 251. 1905.

by water, the solution was evaporated to dryness, and the silica produced was weighed. In a second communication Meyer [1] discusses the possible retention of chlorine by the silica, and shows that that error was avoided. The data obtained by Becker and Meyer follow, with vacuum weights, and a percentage column computed by myself:

$SiCl_4$.	SiO_2.	Per cent.
4. 16733	1. 47597	35. 417
4. 69585	1. 66304	35. 415
4. 91918	1. 74204	35. 413
5. 37434	1. 90349	35. 418
5. 93985	2. 10364	35. 416
6. 73605	2. 38570	35. 417
7. 16361	2. 53606	35. 402
7. 82779	2. 77242	35. 418
		Mean, 35. 4145±. 0017

Hence, Si = 28.231.

There are also two series of the determinations of the density of silicon tetrafluoride, SiF_4 Jaquerod and Tourpaian [2] made their determinations at low pressures, and from the data thus obtained computed the weight of the normal liter of the gas, namely, 4.6929 grammes. From this, by two methods, they derive the molecular weight as follows:

By corresponding densities	SiF_4=104. 68
By critical constants	104. 64
	Mean, SiF_4=104. 66±. 0133

The determinations by Germann and Booth [3] are much more elaborate than those of Jaquerod and Tourpaian, and were made with purer material and subjected to very thorough corrections. Four series of determinations were made on gas of increasing purity, but only the last two were used in the final discussion of the data. In these the following figures are given for the weight in grammes of a "gross" liter of silicon tetrafluoride at approximately 760 mm pressure:

4. 68167	4. 68343
4. 68197	4. 68690
4. 68292	4. 68082
	Mean, 4. 68295±. 00059

From this, reduced to standard form, the weight of the normal liter becomes 4.68397 grammes. Germann and Booth do not go so far as to compute from this figure the molecular weight of the fluoride, but by comparison with the deductions of Jacquerod and Tourpaian it should be approximately

$$SiF_4 = 104.47 \pm .0132$$

From this, the atomic weight of silicon becomes

$$Si = 28.306 \pm .0142$$

This value may require adjustment later. Jacquerod and Tourpaian's figure for the molecular weight gives Si = 28.496, which is certainly too high and need not be considered further.

The ratios relative to the atomic weight of silicon are now—

(1) $4Ag : SiCl_4 :: 100 : 39.4265 \pm .0071$.
(2) $4AgCl : SiCl_4 :: 100 : 29.6125 \pm .0138$.
(3) $SiCl_4 : SiO_2 :: 100 : 35.4145 \pm .0017$.
(4) $SiBr_4 : SiO_2 :: 100 : 17.347 \pm .0027$.
(5) Mol. weight SiF_4, $104.47 \pm .0132$.

[1] Zeitsch. anorg. Chem., 46, 45. 1905. In Vol. 43, p. 242, Meyer discusses the problem of the calculation of atomic weights.
[2] Journ. Chim. Phys., 11, pp. 28, 269. 1913.
[3] Journ. Phys. Chem., 21, 81. 1917.

To reduce these ratios we have

Ag=107.880±.00016	Br=79.9228±.00015
Cl=35.4605±.00011	F=19.011±.0013

From ratio—

2	Si=27.945±.0792
3	28.231±.0045
1	28.293±.0307
5	28.306±.0142
4	28.426±.0115
General mean	Si=28.255±.0025

The rounded-off mean, Si = 28.25, is probably as near the truth as any of the individual values. New determinations of the atomic weight of silicon are evidently desirable.

TITANIUM.

Our knowledge of the atomic weight of titanium is based almost if not quite entirely upon the determinations made by Thorpe. The earlier work of Berzelius,[1] Rose,[2] Mosander,[3] Pierre,[4] and Demoly[5] has now only historical value and for the present purposes may be neglected here. It is sufficiently summarized in the former editions of this work.

In 1883[6] Thorpe published a series of experiments upon titanium tetrachloride, determining three distinct ratios and getting fairly concordant results. The first ratio, which was essentially like Pierre's, by decomposition with water and titration with silver, was in detail as follows:

$TiCl_4$.	*Ag.*	*$TiCl_4$: 100Ag.*
2.43275	5.52797	44.008
5.42332	12.32260	44.015
3.59601	8.17461	44.000
3.31222	7.52721	44.003
4.20093	9.54679	44.004
5.68888	12.92686	44.008
5.65346	12.85490	43.979
4.08247	9.28305	43.978
		Mean, 43.999±.0032

Hence, Ti = 48.022.

The second ratio, which involved the weights of $TiCl_4$ taken in the last five determinations of the preceding series, included the weighing of the silver chloride formed. The $TiCl_4$ proportional to 100 parts of AgCl is given in a third column:

$TiCl_4$.	*AgCl.*	*Ratio.*
3.31222	10.00235	33.114
4.20093	12.68762	33.111
5.68888	17.17842	33.117
5.65346	17.06703	33.125
4.08247	12.32442	33.125
		Mean, 33.118±.0019

Hence, Ti = 48.133.

In the third series the chloride was decomposed by water, and after evaporation to dryness the resulting TiO_2 was strongly ignited:

$TiCl_4$.	*TiO_2.*	*Per cent TiO_2.*
6.23398	2.62825	42.160
8.96938	3.78335	42.181
10.19853	4.30128	42.176
6.56894	2.77011	42.170
8.99981	3.79575	42.176
8.32885	3.51158	42.162
		Mean, 42.171±.0022

Hence, Ti = 48.101.

[1] Gilbert's Annalen, 1823, pp. 67 and 129.
[2] Poggend. Annalen, 15, 145.
[3] Berz. Jahresbericht, 10, 108. 1831.
[4] Ann. Chim. Phys. (3), 20, 257. 1847.
[5] Ann. Chem. Pharm., 72, 214. 1849.
[6] Ber. Deutsch. chem. Gesell., 16, 3014. 1883.

Some two years later Thorpe published his work more in detail,[1] and added a set of determinations, like those made upon the chloride, in which titanium tetrabromide was studied. Three ratios were measured, as was the case with the chloride. In the first, the bromide was decomposed by water and titrated with a silver solution.

$TiBr_4$.	Ag.	$TiBr_4 : 100Ag$.
2.854735	3.34927	85.235
3.120848	3.66122	85.241
4.731118	5.55097	85.230
6.969075	8.17645	85.234
6.678099	7.83493	85.234
		Mean, 85.235±.0027

Hence, Ti = 48.115.

In the four last experiments of the preceding series, the silver bromide formed was weighed. The third column gives the $TiBr_4$ proportional to 100 parts of AgBr.

$TiBr_4$.	$AgBr$.	Ratio.
3.120848	6.375391	48.951
4.731118	9.663901	48.957
6.969075	14.227716	48.982
6.678099	13.639956	48.959
		Mean, 48.962±.0049

Hence, Ti = 48.117.

For the third ratio the bromide was decomposed by water; and after evaporation with ammonia the residual titanic oxide was ignited and weighed:

$TiBr_4$.	TiO_2.	Per cent TiO_2.
6.969730	1.518722	21.790
8.836783	1.923609	21.768
9.096309	1.979513	21.762
		Mean, 21.773±.0062

Hence, Ti = 48.073.

The following ratios are now available for computing the atomic weight of titanium:

(1) $4Ag : TiCl_4 :: 100 : 43.999 \pm .0032$.
(2) $4AgCl : TiCl_4 :: 100 : 33.118 \pm .0019$.
(3) $TiCl_4 : TiO_2 :: 100 : 42.171 \pm .0022$.
(4) $4Ag : TiBr_4 :: 100 : 85.235 \pm .0027$.
(5) $4AgBr_4 : TiBr_4 :: 100 : 48.962 \pm .0049$.
(6) $TiBr_4 : TiO_2 :: 100 : 21.773 \pm .0062$.

Reducing these ratios with Ag = 107.880 ± .00016; Cl = 35.4605 ± .00011; and Br = 79.9228 ± .00015 we have—

From ratio—	
1	Ti = 48.022 ± .0138
6	48.073 ± .0292
3	48.101 ± .0072
4	48.115 ± .0117
5	48.117 ± .0369
2	48.133 ± .0110
General mean	Ti = 48.099 ± .0049

This value may be rounded off to Ti = 48.1.

[1] Journ. Chem. Soc., 47, 108 and 129. 1885.

GERMANIUM.

The data relative to the atomic weight of germanium are imperfect, and due entirely to the discoverer of the element, Winkler.[1] The pure tetrachloride was decomposed by sodium carbonate, mixed with a known excess of standard silver solution, and then titrated back with ammonium sulphocyanate. The data given are as follows:

$GeCl_4$.	*Cl found.*	*Per cent Cl.*
0.1067	0.076112	66.177
.1258	.083212	66.146
.2223	.147136	66.188
.2904	.192190	66.182
		Mean, 66.173

Hence, Ge = 72.504.

ZIRCONIUM.

The atomic weight of zirconium has been determined by Berzelius, Hermann, Marignac, Weibull, Bailey, Venable, and Venable and Bell. The determinations by Berzelius[2] and Hermann[3] may be neglected for present purposes.

Marignac's determinations[4] were based upon analyses of the double fluoride of zirconium and potassium. His weights are as follows:

1.000 grm.	gave	0.431 grm.	ZrO_2 and	0.613 grm.	K_2SO_4.
2.000	"	.864	"	1.232	"
.654	"	.282	"	.399	"
5.000	"	2.169	"	3.078	"

These figures give us three ratios. A, the ZrO_2 from 100 parts of salt; B, the K_2SO_4 from 100 parts of salt; and C, the ZrO_2 proportional to 100 parts of K_2SO_4:

A.	*B.*	*C.*
43.100	61.300	70.310
43.200	61.600	70.130
43.119	61.000	70.677
43.380	61.560	70.468
Mean, 43.200±.043	Mean, 61.365±.094	Mean, 70.396±.079
Hence Zr=90.03	91.53	90.67

Weibull[5] ignited zirconium sulphate, and also made a similar set of experiments with the selenate, obtaining results as follows:

Sulphate. $Zr(SO_4)_2$.

Sulphate.	*ZrO_2.*	*Per cent.*
1.5499	0.6684	43.126
1.5445	.6665	43.153
2.1683	.9360	43.168
1.0840	.4670	43.081
.7913	.3422	43.321
.6251	.2695	43.113
.4704	.2027	43.091
		Mean, 43.150±.0207

Hence, Zr = 89.54.

Selenate. $Zr(SeO_4)_2$.

Selenate.	*ZrO_2.*	*Per cent.*
1.0212	0.2323	32.540
.8418	.2744	32.597
.6035	.1964	32.544
.8793	.2870	32.640
.3089	.1003	32.470
		Mean, 32.558±.0192

Hence, Zr = 90.79.

[1] Journ. prakt. Chem. (2), 34, 177. 1886.
[2] Poggend. Annal., 4, 126. 1825.
[3] Journ. prakt. Chem., 31, 77. Berz. Jahresb., 25, 147.
[4] Ann. Chim. Phys. (3), 60, 270. 1860.
[5] Lund. Arsskrift, Vol. 18. 1881–'82.

Bailey [1] also ignited the sulphate, after careful investigation of his material and of the conditions needful to insure success. He found that the salt was perfectly stable at 400°, while every trace of free sulphuric acid was expelled at 350°. The chief difficulty in the process arises from the fact that the zirconia produced by the ignition is very light, and easily carried off mechanically, so that the percentage found is likely to be too low. This difficulty was avoided by the use of a double crucible, the outer one retaining particles of zirconia which otherwise might be lost. The results, corrected for buoyancy of the air, are as follows:

Sulphate.	*ZrO_2.*	*Per cent.*
2.02357	0.87785	43.381
2.6185	1.1354	43.360
2.27709	.98713	43.350
2.21645	.96152	43.385
1.75358	.76107	43.402
1.64065	.7120	43.397
2.33255	1.01143	43.361
1.81105	.78485	43.337
		Mean, 43.372±.0056

Hence, Zr = 90.65.

This, combined with previous determinations, gives—

Weibull	43.150±.0207
Bailey	43.372±.0056
General mean	43.358±.0054

Venable [2] determined the atomic weight of zirconium by analysis of the oxychloride, $ZrOCl_2.3H_2O$. This compound was purified by crystallization from hot hydrochloric acid and dried in a stream of hydrochloric acid gas. It was then dissolved in water, and after evaporating the solution to dryness in a platinum crucible the residue was converted into zirconia by prolonged ignition. The data are subjoined:

Weight $ZrOCl_2.3H_2O$.	*Weight ZrO_2.*	*Per cent ZrO_2.*
5.25762	2.78450	52.961
3.53994	1.87550	52.981
3.25036	1.72435	53.051
1.52245	.80708	53.012
2.98802	1.58274	52.969
2.11371	1.11920	52.949
2.38139	1.26161	52.978
1.90285	1.00958	53.055
2.61847	1.38658	52.954
1.07347	.56840	52.951
		Mean, 52.986±.0085

Hence, Zr = 90.819.

The determinations by Venable and Bell [3] were based upon analyses, by the standard method, of zirconium tetrachloride. Their weights, reduced to a vacuum, and the ratio $4Ag : ZrCl_4 :: 100 : x$ are as follows:

$ZrCl_4$	*Ag.*	*Ratio.*
5.55372	10.26178	54.121
3.78445	6.99198	54.125
2.97546	5.49645	54.134
7.22480	13.34222	54.150
6.35532	11.73094	54.175
6.78989	12.54259	54.135
5.65352	10.44718	54.115
2.76975	5.11980	54.099
4.30337	7.95180	54.106
4.31934	7.98115	54.119
2.42721	4.48516	54.116
4.80724	8.87607	54.160
2.35598	4.35052	54.154
		Mean, 54.1315±.0043

Hence, Zr = 91.746.

[1] Proc. Roy. Soc., 46, 74. Chem. News, 60, 32. [2] Journ. Amer. Chem. Soc., 20, 119. 1898. [3] Journ. Amer. Chem. Soc., 39, 1598. 1917.

For computing the atomic weight of zirconium we now have the following ratios:

(1) Percentage ZrO_2 in $Zr(SO)_2$, $43.358 \pm .0054$.
(2) Percentage ZrO_2 in $Zr(SeO_4)_2$, $32.558 \pm .0192$.
(3) Percentage ZrO_2 from K_2ZrF_6, $43.200 \pm .043$.
(4) Percentage K_2SO_4 from K_2ZrF_6, $61.365 \pm .094$.
(5) Percentage ZrO_2 in $ZrOCl_2.3H_2O$, $52.986 \pm .0085$.
(6) $4Ag : ZrCl_4 :: 100 : 54.1315 \pm .0043$.
(7) $K_2SO_4 : ZrO_2 :: 100 : 70.396 \pm .0079$.

The antecedent values for reduction of these ratios are—

Ag=107.880±.00016 K=39.0975±.00011
Cl=35.4605±.00011 F=19.011±.0013
S=32.0650±.00012 Se=79.176±.0029
H=1.0078±.00001

Hence,

From ratio—	
3	Zr=90.206±.2390
1	90.575±.0193
7	90.672±.0138
2	90.790±.0804
5	90.819±.0302
4	91.606±.4350
6	91.746±.0116
General mean	Zr=91.1745±.0080

This mean is unsatisfactory because the values are too divergent. That from ratio 6 appears to be much the best, but it is not absolutely final. More work on zirconium is needed.

TIN.

The atomic weight of tin has been determined by means of the oxide, the chloride, the bromide, the sulphide and the stannichlorides of potassium and ammonium.

The composition of stannic oxide has been fixed in two ways: by synthesis from the metal and by reduction in hydrogen. For the first method we may consider the work of Berzelius, Mulder and Vlaanderen, Dumas, Van der Plaats and Bongartz and Classen.

Berzelius[1] oxidized 100 parts of tin by nitric acid, and found that 127.2 parts of SnO_2 were formed. Hence, Sn=117.65.

The work done by Mulder and Vlaanderen[2] was done in connection with a long investigation into the composition of Banca tin, which was found to be almost absolutely pure. For the atomic weight determinations, however, really pure tin was taken prepared from pure tin oxide. This metal was oxidized by nitric acid, with the following results. One hundred parts of tin gave of SnO_2:

127.56—Mulder
127.56—Vlaanderen
127.43—Vlaanderen

Mean, 127.517±.029

Hence, Sn=116.3.

Dumas[3] oxidized pure tin by nitric acid in a flask of glass. The resulting SnO_2 was strongly ignited, first in the flask and afterwards in platinum. His weighings, reduced to the foregoing standard, give for dioxide from 100 parts of tin the amounts stated in the third column:

Sn.	*SnO_2.*	*Ratio.*
12.443	15.820	127.14
15.976	20.301	127.07

Mean, 127.105±.024

Hence, Sn=118.06.

[1] Poggend. Annal., 8, 177. [2] Journ. prakt. Chem., 49, 35. 1849. [3] Ann. Chem. Pharm., 113, 26.

In an investigation later than that previously cited, Vlaanderen[1] found that when tin was oxidized in glass or porcelain vessels, and the resulting oxide ignited in them, traces of nitric acid were retained. When, on the other hand, the oxide was strongly heated in platinum, the latter was perceptibly attacked, so much so as to render the results uncertain. He therefore, in order to fix the atomic weight of tin, reduced the oxide by heating it in a porcelain boat in a stream of hydrogen. Two experiments gave Sn = 118.08, and Sn = 118.24. These become, if reduced to the above common standard,

127.100
127.064
Mean, 127.082 ± .012

Hence, Sn = 118.16.

Van der Plaats[2] prepared pure stannic oxide from Banca tin, and upon the material obtained made two series of experiments; one by reduction and one by oxidation. The results, with vacuum weights, are as follows, the ratio between Sn and SnO_2 appearing in the third column:

Oxidation series.

Sn.	*SnO_2.*	*Ratio.*
9.6756	12.2967	127.091
12.7356	16.1885	127.114
23.4211	29.7667	127.093

Reduction series.

SnO_2.	*Sn.*	*Ratio.*
5.5015	4.3280	127.114
4.9760	3.9145	127.117
3.8225	3.0078	127.086
2.9935	2.3553	127.096

Mean of both series as one, 127.102 ± .0033

Hence, Sn = 118.07.

The reductions were effected in a porcelain crucible.

Bongartz and Classen[3] purified tin by electrolysis, and oxidized the electrolytic metal by means of nitric acid. The oxide found was dried over a water-bath, then heated over a weak flame, and finally ignited for several hours in a gas-muffle. Some reduction experiments gave values which were too low. The oxidation series was as follows, with the usual ratio stated in a third column:

Sn.	*SnO_2.*	*Ratio.*
2.5673	3.2570	126.865
3.8414	4.8729	126.852
7.3321	9.2994	126.831
5.4367	6.8962	126.845
7.3321	9.2994	126.831
9.8306	12.4785	126.935
11.2424	14.2665	126.896
5.5719	7.0685	126.860
9.8252	12.4713	126.932
4.3959	5.5795	126.925
6.3400	8.0440	126.877

Mean, 126.877 ± .0080

Hence, Sn = 119.06.

We now have six series of experiments giving the amount of SnO_2 formed from 100 parts of tin. To Berzelius' single determination may be assigned the weight of one experiment in Mulder and Vlaanderen's series :

Berzelius	127.200 ± .041
Mulder and Vlaanderen	127.517 ± .029
Dumas	127.105 ± .024
Vlaanderen	127.082 ± .012
Van der Plaats	127.102 ± .0033
Bongartz and Classen	126.877 ± .0080
General mean	127.076 ± .0026

[1] Jahresbericht, 1858, 183. [2] Compt. Rend., 100, 52. 1885. [3] Berichte Deutsch. chem. Gesell., 21, 2900. 1888.

Dumas, in the paper previously quoted, also gives the results of some experiments with stannic chloride, $SnCl_4$. This was titrated with a solution containing a known weight of silver. From the weighings given, 100 parts of silver correspond to the quantities of $SnCl_4$ named in the third column :

$SnCl_4$.	*Ag.*	*Ratio.*
1.839	3.054	60.216
2.665	4.427	60.199
		Mean, 60.207±.006

Hence, Sn = 117.96.

Tin tetrabromide and the stannichlorides of potassium and ammonium were all studied by Bongartz and Classen; who, in each compound, carefully purified, determined the tin electrolytically. The data given are as follows, the percentage columns being added by myself:

Tin Tetrabromide.

$SnBr_4$ taken.	*Sn found.*	*Per cent Sn.*
8.5781	2.3270	27.127
9.5850	2.6000	27.126
9.9889	2.7115	27.145
10.4914	2.8445	27.113
16.8620	4.5735	27.123
16.6752	4.5236	27.119
11.1086	3.0125	27.116
10.6356	2.8840	27.113
11.0871	3.0060	27.123
19.5167	5.2935	27.128
		Mean, 27.123±.0020

Hence, Sn = 118.98.

Potassium Stannichloride.

K_2SnCl_6.	*Sn found.*	*Per cent Sn.*
2.5718	0.7472	29.054
2.2464	.6524	29.042
9.3353	2.7100	29.030
12.1525	3.5285	29.035
12.4223	3.6070	29.036
15.0870	4.3812	29.040
10.4465	3.0330	29.034
18.9377	5.5029	29.058
18.4743	5.3630	29.029
17.6432	5.1244	29.045
		Mean, 29.040±.0021

Hence, Sn = 119.07.

Ammonium Stannichloride.

Am_2SnCl_6.	*Sn found.*	*Per cent Sn.*
1.6448	0.5328	32.393
1.8984	.6141	32.347
2.0445	.6620	32.381
2.0654	.6690	32.391
2.0058	.6496	32.386
2.4389	.7895	32.371
4.0970	1.3254	32.351
3.4202	1.1078	32.390
3.6588	1.1836	32.349
1.5784	.5108	32.362
7.3248	2.3710	32.370
13.1460	4.2528	32.351
11.9483	3.8650	32.348
18.4747	5.9788	32.362
18.6635	6.0415	32.371
17.8894	5.7923	32.378
		Mean, 32.369±.0088

Hence, Sn = 119.1.

One other method of determination for the atomic weight of tin was employed by Bongartz and Classen. Electroytic tin was converted into sulphide, and the sulphur so taken up was oxidized by means of hydrogen peroxide, by Classen's method, and weighed as barium sulphate. The results, as given by the authors, are subjoined :

Sn taken.	*Per cent of S gained.*
2.6285	53.91
.7495	53.87
1.4785	53.94
2.5690	53.94
2.1765	53.85
1.3245	53.88
.9897	53.83
2.7160	53.86
	Mean, 53.885±.0098

This percentage of sulphur, however, was computed from weighings of barium sulphate. What values were assigned to the atomic weights of barium and sulphur is not stated, but as Meyer and Seubert's figures are used for other elements throughout this paper, we may assume that they apply here also. Putting O=15.96, S=31.98, and Ba=136.86, the 53.885 per cent of sulphur becomes 392.056±.0713 of $BaSO_4$, the compound actually weighed. This gives us the ratio—

$$Sn : 2BaSO_4 :: 100 : 392.056 \pm .0713$$

as the real result of the experiments, from which, with the later values for Ba, S and O, the atomic weight of tin may be calculated.

A single determination of the atomic weight of tin, made by Schmidt,[1] ought not to be overlooked, although it was only incidental to his research upon tin sulphide. In one experiment, 0.5243 grm. Sn gave 0.6659 SnO_2. Hence, Sn=118.49. This lies about midway between the two sets of values already computed.

The determinations of the atomic weight of tin by Briscoe[2] were made by decomposing stannic chloride by water, and titrating the solution with a standard solution of silver. Oxalic acid, or Rochelle salt was used to prevent the precipitation of stannic oxide. His weights, reduced to a vacuum, and the ratio $4Ag : SnCl_4 :: 100 : x$ follow :

$SnCl_4$.	*Ag.*	*Ratio.*
9.02435	14.9475	60.3736
9.39855	15.5666	60.3764
10.32760	17.1058	60.3748
9.17005	15.1880	60.3769
6.68995	11.0808	60.3742
9.33130	15.4570	60.3694
7.77450	12.8764	60.3779
9.22730	15.2840	60.3723
7.55785	12.5183	60.3744
9.11535	15.0983	60.3732
9.22875	15.2866	60.3715
9.21890	15.2696	60.3742
11.29055	18.7017	60.3715
9.89635	16.3912	60.3760
9.43385	15.6250	60.3767
		Mean, 60.3742±.0004

Hence, Sn=118.691.

For the same ratio Dumas' analyses give the value 60.207±.0060. Combined with Briscoe's value, the general mean is 60.3735±.00039.

[1] Ber. Deutsch. Chem. Ges., 27, 2743. 1894.

[2] Journ. Chem. Soc., 107, 63. 1915.

Baxter and Starkweather[1] also analyzed stannic chloride, but by electrolysis; collecting the tin on a weighed mercury cathode. With vacuum weights their data are as follows:

$SnCl_4$.	Sn.	Per cent Sn.
11.64269	5.30498	45.565
13.5943	6.1935	45.560
10.0897	4.5971	45.561
11.4319	5.2080	45.557
12.2869	5.5983	45.563
12.20889	5.56286	45.564
10.7469	4.8965	45.562
11.54233	5.25846	45.558
15.65437	7.13198	45.559
16.23310	7.39664	45.565
17.29151	7.87850	45.563
15.04889	6.85695	45.565
18.36074	8.36507	45.560
21.58929	9.83676	45.563
17.22210	7.84718	45.565
15.70516	7.15589	45.564
		Mean, 45.562±.00045

Hence, Sn = 118.715.

For tin there are now the following available ratios:

(1) $Sn : SnO_2 :: 100 : 127.076 \pm .0026$.
(2) $4Ag : SnCl_4 :: 100 : 60.3735 \pm .00039$.
(3) $SnCl_4 : Sn :: 100 : 45.562 \pm .00045$.
(4) $SnBr_4 : Sn :: 100 : 27.123 \pm .0020$.
(5) $K_2SnCl_6 : Sn :: 100 : 29.040 \pm .0021$.
(6) $(NH_4)_2SnCl_6 : Sn :: 100 : 32.369 \pm .0088$.
(7) $Sn : 2BaSO_4 :: 100 : 392.056 \pm .0713$.

To reduce these we have—

Ag=107. 880±.00016	N= 14.0081±.00008
Cl= 35.4605±.00011	S= 32.0650±.00012
Br= 79.9228±.00015	Ba=137.358±.0023
K= 39.0975±.00011	H= 1.0078±.00001

Hence,

From ratio—	
1	Sn=118.186±.0113
2	118.681±.0019
3	118.715±.0016
4	118.981±.0094
5	119.074±.0093
7	119.076±.0876
6	119.099±.0359
General mean	118.708±.0012

This general mean is almost identical with the values found in the two most recent investigations. Their low probable errors give them controlling weight in the combination. For a careful discussion of sources of error in the earlier determinations, the paper by Briscoe should be consulted.

ADDENDA.

Since the preceding pages were put in type, two new papers on the atomic weight of tin have appeared.[2] First, Brauner and Krepelka, by a series of electrolyses of ammonium stannichloride, obtained unsatisfactory values. By analyses of stannic bromide, however, they secured better results. The data, with vacuum weights, are as follows:

[1] Proc. Nat. Acad., 2, 718. 1916. In full in Journ. Amer. Chem. Soc., May, 1920.
[2] Jour. Amer. Chem. Soc., 42, pp. 917–928. 1920.

$SnBr_4$.	Ag.	At. Wt. Sn.	
2.11624	2.08430	118.55	Rejected.
1.11964	1.10206	118.73	
1.97428	1.94359	118.67	
2.35469	2.31788	118.71	
	Mean of last 3,	118.70	

This series of determination is preliminary. In the second paper, by Krepelka alone, the following figures were obtained:

$SnBr_4$.	Ag.	At. Wt. Sn.
5.11788	5.03796	118.702
2.46875	2.43035	118.674
.99510	.97961	118.679
1.69834	1.67172	118.727
3.54265	3.48737	118.697
3.18280	3.76199	118.717
	Mean,	118.699

The values found for tin in these two series confirm the determinations made by Briscoe and by Baxter and Starkweather.

THORIUM.

The earlier determinations of the atomic weight of thorium by Berzelius, Chydenius, Delafontaine, and Hermann,[1] have now only historical interest, and need no detailed consideration here.

The modern determinations begin with those of Cleve,[2] who analyzed the sulphate and oxalate of thorium. The anhydrous sulphate, calcined, gave the subjoined percentages of thoria:

62.442	62.470
62.477	62.357
62.430	62.366

Mean, 62.423±.014

Hence, Th=234.01.

The oxalate was subjected to a combustion analysis, whereby both thoria and carbonic acid could be estimated. From the direct percentages of these constituents no accurate value can be deduced, there having undoubtedly been moisture in the material studied. From the ratio between CO_2 and ThO_2, however, good results are attainable. This ratio I put in a fourth column, making the thoria proportional to 100 parts of carbon dioxide:

Oxalate.	ThO_2.	CO_2.	Ratio.
1.7135	1.0189	0.6736	151.262
1.3800	.8210	.5433	151.114
1.1850	.7030	.4650	151.183
1.0755	.6398	.4240	150.896
		Mean,	151.114±.053

Hence, Th=234.02.

In 1882 Nilson's determinations appeared.[3] This chemist studied both the anhydrous sulphate and the salt with nine molecules of water, using the usual calcination method, but guarding especially against the hygroscopic character of the dry $Th(SO_4)_2$ and the calcined ThO_2. The hydrated sulphate gave results as follows:

$Th(SO_4)_2.9H_2O$.	ThO_2.	Per cent ThO_2.
2.0549	0.9267	45.097
2.1323	.9615	45.092
3.0017	1.3532	45.081
2.7137	1.2235	45.086
2.6280	1.1849	45.088
1.9479	.8785	45.099
	Mean,	45.091±.0019

Hence, Th=232.65.

[1] These determinations are fully discussed in the former editions of this work, *q. v.*

[2] K. Svensk. Vet. Akad. Handl., Bd. 2, No. 6, 1874.

[3] Ber. Deutsch. chem. Gesell., 15, 2519. 1882.

The anhydrous sulphate gave data as follows:

$Th(SO_4)_2$.	ThO_2.	Per cent ThO_2.
1.4467	0.9013	62.300
1.6970	1.0572	62.298
2.0896	1.3017	62.294
1.5710	.9787	62.298
		Mean, 62.297±.0009

Hence, Th=232.58.

The last four determinations appear again in a paper published five years later by Krüss and Nilson,[1] who, however, give four more made upon material obtained from a different source. The new data are subjoined:

$Th(SO_4)_2$.	ThO_2.	Per cent ThO_2.
1.1630	0.7245	62.296
.8607	.5362	62.298
1.5417	.9605	62.301
1.5217	.9479	62.292
		Mean, 62.297±.0013

Hence, Th=232.58.

Urbain,[2] who purified his material by crystallizing thorium acetylacetonate from solution in chloroform, gives the following analyses of the anhydrous sulphate, effected by calcination:

$Th(SO_4)_2$.	ThO_2.	Per cent ThO_2.
1.0925	0.6815	62.374
.5926	.3699	62.420
1.0230	.6384	62.405
		Mean, 62.400±.0096

Hence, Th=233.75.

Meyer and Gumperz,[3] in order to determine whether thorium is complex or not, prepared the octohydrated sulphate from material of diverse origin, and analyzed it by dehydration and calcination. Their data, which I give as one series, represent, first, six experiments upon preparations obtained by fractional precipitation as chromate; and, secondly, six analyses of the sulphate prepared from three samples of thorium chloride. I give here only the weights of the anhydrous sulphate and the oxide, for the reason that the hydration of the compound was too irregular to yield good values for the atomic weight of thorium:

$Th(SO_4)_2$.	ThO_2.	Per cent ThO_2.
0.9301	0.5793	62.284
.9927	.6184	62.295
1.0344	.6442	62.278
.9349	.5821	62.263
.6680	.4160	62.276
.4296	.2676	62.291
.9199	.5730	62.289
.7647	.4764	62.299
1.0650	.6633	62.300
.7758	.4834	62.310
.8824	.5496	62.285
.5545	.3454	62.290
		Mean, 62.288±.0024

Hence, Th=232.48.

In an early paper Brauner [4] and later Baskerville [5] claimed to have fractionated thoria into different component earths, which varied widely in atomic weight and physical properties. These claims, however, were not fully substantiated. Recently, Brauner,[6] in an exhaustive critical discussion of the atomic weight of thorium, has published the details of his work, and offered an explanation of the discordances. Omitting variant series of determinations, and

[1] Ber. Deutsch. chem. Gesell., 20, 1665. 1887.
[2] Ann. Chim. Phys. (7), 19, 223. 1900.
[3] Ber. Deutsch. Chem. Ges., 38, 817. 1905.
[4] Proc. Chem. Soc., 17, 67.
[5] Journ. Amer. Chem. Soc., 23, 761, and 26, 922.
[6] Abegg's Handbuch, 3, (2), 805.

also his analyses of thorium oxalate, Brauner gives two sets of analyses of the sulphate which he regards as satisfactory. The data are as follows:

Series 1.

$Th(SO_4)_2$.	ThO_2.	Per cent ThO_2.
1.7165	1.0699	62.330
.94702	.59075	62.380
		Mean, 62.355±.0170

Hence, Th = 233.12.

Series 2.

$Th(SO_4)_2$.	ThO_2.	Per cent ThO_2.
1.93405	1.2044	62.282
1.14252	.71152	62.276
1.89330	1.17925	62.285
1.96495	1.22395	62.289
		Mean, 62.283±.0027

Hence, Th = 232.43.

These figures combine with those of previous investigations thus:

Cleve	62.423±.0140
Nilson	62.297±.0009
Krüss and Nilson	62.297±.0013
Urbain	62.400±.0096
Meyer and Gumperz	62.288±.0024
Brauner, 1	62.355±.0170
Brauner, 2	62.283±.0027
General mean	62.299±.0007

A different procedure for determining the atomic weight of thorium was adopted by Hönigschmid,[1] who made analyses of the bromide by the standard method. His figures, with vaccum weights, and the usual ratios are as follows

$ThBr_4$.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
5.11577	4.00046	6.96402	127.879	73.460
3.85077	3.01126	5.24210	127.879	73.459
4.9327	3.82643	6.66091	127.881	73.462
4.70546	3.67975	6.40573	127.874	73.457
5.12854	4.01057	6.98157	127.876	73.458
4.18710	3.27425	5.69982	127.880	73.460
3.66181	2.86343	4.48479	127.882	73.460
3.74590	2.92948	5.09931	127.869	73.459
4.47249	3.49762	6.08888	127.872	73.452
5.02409	3.92861	6.83873	127.885	73.465
5.34994	4.18375	7.28310	127.874	73.457
4.32353	3.38105	5.88552	127.875	73.460
			Mean, 127.877±.0009	73.459±.0006

Hence, from Ag ratio, Th = 232.124.

From AgBr ratio, Th = 232.141.

The ratios from which to compute the atomic weight of thorium are now as follows:

(1) $4CO_2 : ThO_2 :: 100 : 151.114 \pm .053$.
(2) $Th(SO_4)_2.9H_2O : ThO_2 :: 100 : 45.091 \pm .0019$.
(3) $Th(SO_4)_2 : ThO_2 :: 100 : 62.299 \pm .0007$.
(4) $4Ag : ThBr_4 :: 100 : 127.877 \pm .0009$.
(5) $4AgBr : ThBr_4 :: 100 : 73.459 \pm .0006$.

To reduce these ratios we have—

Ag = 107.880± .00016
Br = 79.9228±.00015
S = 32.0650±.00012
C = 12.0025±.00019
H = 1.0078±.00001

[1] Zeitsch. Elektrochem., 22, 18, 1916. From abstract by Baxter in Journ. Amer. Chem. Soc., 39, 340.

Hence,

From ratio—	
4	Th=232.124±.0040
5	232.141±.0056
3	232.607±.0058
2	232.647±.0145
1	234.021±.0933
General mean	Th=232.192±.0028

This general mean is slightly higher than the value derived from Hönigschmid's analyses alone, which, on chemical grounds, appear to be the best. It would hardly be wise, however, in the light of present knowledge, to reject the values found by analyses of thorium sulphate. They, therefore, receive proper recognition in the final combination. The difference between the general mean and the value given by Hönigschmid's work alone, is only about 1 part in 4,000.

The foregoing discussion relates only to what may be called *normal* thorium, which appears to be a perfectly definite element. The thorium contained in uranium ores, however, contains an admixture of its radioactive isotope, ionium, an element which is chemically undistinguishable from thorium, except that it has a lower atomic weight. With thorium from uranium ores Hönigschmid has made several atomic weight determinations and obtained the following results:

Th(Io)Br$_4$.	*Ag.*	*AgBr.*	*Ag ratio.*	*AgBr ratio.*
3.21504	2.51702	4.38166	127.731	73.373
2.73569	2.14178	3.72848	127.729	73.372
4.27574	3.34762	5.82951	127.724	73.371
			Mean, 127.728	73.372

From the Ag ratio Th(Io) = 231.481.

From the AgBr ratio Th(Io) = 231.488.

The atomic weight of ionium free from thorium would doubtless be smaller still, perhaps as low as 231.2, or even a little lower. On this question further evidence is needed.

PHOSPHORUS.

The material from which to calculate the atomic weight of phosphorus is by no means abundant. Berzelius, in his Lehrbuch,[1] adduces only his own experiments upon the precpitation of gold by phosphorus, and ignores all the earlier work relating to the composition of the phosphates. These experiments have been considered with reference to gold.

Pelouze,[2] in a single titration of phosphorus trichloride with a standard solution of silver, obtained a wholly erroneous result; and Jacquelain,[3] in his similar experiments, did even worse. Schrötter's criticism upon Jacquelain sufficiently disposes of the latter.[4]

Only the determinations made by Schrötter, Dumas, Van der Plaats, Ter Gazarian and Baxter and his colleagues remain to be considered.

Schrötter[5] burned pure amorphous phosphorus in dry oxygen, and weighed the pentoxide thus formed. One gramme of P yielded P_2O_5 in the following proportions:

2.28909	2.28738
2.28783	2.28848
2.29300	2.28856
2.28831	2.28959
2.29040	2.28872

Mean, 2.289186±.00033

Hence, P = 31.027.

Dumas[6] prepared pure phosphorus trichloride by the action of dry chlorine upon red phosphorus. The portion used in his experiments boiled between 76° and 78°. This was titrated with a standard solution of silver in the usual manner. Dumas published weights, from which I calculate the figures given in the third column, representing the quantity of trichloride proportional to 100 parts of silver:

[1] 5th ed., 1188.
[2] Compt. Rend., 33, 693.
[3] Compt. Rend., 20, 1047.
[4] Journ. prakt. Chem., 57, 315.
[5] Journ. prakt. Chem., 53, 435. 1851.
[6] Ann. Chem. Pharm., 113, 29. 1860.

PCl_3.	Ag.	Ratio.
1.787	4.208	42.4667
1.466	3.454	42.4435
2.056	4.844	42.4443
2.925	6.890	42.4528
3.220	7.582	42.4690
		Mean, 42.4553±.0036

Hence, P=31.021.

By Van der Plaats [1] three methods of determination were adopted, and all weights were reduced to a vacuum. First, silver was precipitated from a solution of the sulphate by means of phosphorus. The latter had been twice distilled in a current of nitrogen. The silver, before weighing, was heated to redness. The phosphorus equivalent to 100 parts of silver is given in the third column:

P	Ag.	Ratio.
0.9096	15.8865	5.7256
.5832	10.1622	5.7389
		Mean, 5.7322±.0045

Hence, P=30.920.

The second method consisted in the analysis of silver phosphate; but the proceess is not given. Van der Plaats states that it is difficult to be sure of the purity of this salt.

Ag_3PO_4.	Ag.	Per cent.
6.6300	5.1250	77.300
12.7170	9.8335	77.326
		Mean, 77.313±.0088

Hence, P=30.970.

In the third set of determinations, yellow phosphorus was oxidized by oxygen at reduced pressure, and the resulting P_2O_5 was weighed:

P.	P_2O_5.	Ratio.
10.8230	24.7925	2.29072
7.7624	17.7915	2.29201

Hence, P=30.975.

As these figures fall within the range of Schrötter's, they may be averaged in with his series, the entire set of 12 determinations giving a mean of 2.28955±.00032.

Ter Gazarian [2] determined the density of gaseous phosphine, from which its molecular weight is deducible. For the weight of the normal liter, in grammes, he found—

1.52955	1.52944
1.52907	1.52907
1.52933	1.52933

Mean, 1.52930±.000054

From these figures, reduced by means of the critical constants, Ter Gazarian finds PH_3=33.931. The probable error is 0.0012. Hence, P=30.908.

Baxter and Jones [3] based their determinations of the atomic weight of phosphorus upon analyses of silver phosphate. This salt was dissolved, and the silver precipitated and weighed as bromide, and in one experiment as chloride.

The weights, in vacuo, and the ratios are as follows:

Ag_3PO_4.	AgBr.	Ratio.
6.20166	8.34490	134.558
6.35722	8.55419	134.559
5.80244	7.80819	134.567
5.05845	6.80685	134.564
7.15386	9.62694	134.570
7.20085	9.68947	134.560
6.20182	8.34522	134.561
5.20683	7.00605	134.555
		Mean, 134.562±.0012

Hence, P=31.058.

[1] Compt. Rend., 100, 52. 1885.

[2] Journ. Chim. Phys., 7, 337. 1909. See also note in Journ. Chim. Phys., 9, 100; in which Ter Gazarian replies to criticisms.

[3] Journ. Amer. Chem. Soc., 32, 298. 1910.

Ag_3PO_4.	$AgCl$.	Ratio.
3.34498	3.43544	102.704±.0034

Hence, P=31.060.

The probable error assigned to the last ratio is that of one experiment in the bromide series.

Two years later Baxter, Moore, and Boylston [1] published three series of analyses of phosphorus tribromide, with all the usual precautions to insure accuracy. Their figures, with vacuum weights, are as follows:

Series 1.

PBr_3.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
5.95293	7.11504	12.38560	83.6668	48.0633
4.71056	5.63022	9.80058	83.6657	48.0641
4.72373	5.64583	9.82830	83.6676	48.0624
6.47622	7.74048	13.47428	83.6669	48.0636
4.61956	5.52140	9.61143	83.6665	48.0632
7.62060	9.10849	.....	83.6648	.....
3.83321	4.58163	7.97563	83.6648	48.0615
4.72578	5.64835	9.83261	83.6666	48.0623
			Mean, 83.6662±.00024	48.0629±.00022

Series 2.

PBr_3.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
3.21808	3.84649	6.69553	83.6628	48.0631
5.77604	6.90379	12.01761	83.6648	48.0631
5.51730	6.59456	11.47946	83.6644	48.0624
7.15048	8.54653	.....	83.6653	.....
7.94753	9.49930	16.53569	83.6644	48.0629
4.30924	5.15074	8.96595	83.6625	48.0623
			Mean, 83.6640±.00031	48.0628±.00010

Series 3.

PBr_3.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
4.39626	5.25447	9.14663	83.6671	48.0643
7.07758	8.45957	14.72642	83.6636	48.0604
4.19854	5.01851	8.73586	83.6611	48.0610
7.26540	8.68405	15.11725	83.6637	48.0603
7.75072	9.26406	16.12737	83.6644	48.0594
			Mean, 83.6640±.00065	48.0611±.00057

Combining these series we have—

$$3Ag:PBr_3::100:83{\cdot}6653 \pm .00019$$

Hence, P=31.006.

$$3AgBr:PBr_3::100:48.0627 \pm .00009$$

Hence, P=31.021.

The preceding investigation was shortly followed by one by Baxter and Moore,[2] who made similar analyses of phosphorus trichloride.

Their data are as follows:

Series 1.

PCl_3	Ag.	Ratio.
3.60897	8.50148	42.4511
3.49255	8.22734	42.4505
3.80549	8.96427	42.4517
4.64502	10.94212	42.4508
3.99011	9.39943	42.4505
3.38036	7.96301	42.4508
		Mean, 42.4509±.00012

Hence, P=31.004.

[1] Proc. Amer. Acad., 47, 585. 1912.

[2] Journ. Amer. Chem. Soc., 34, 1644.

Series 2 and 3.

PCl_3	*Ag.*	*AgCl.*	*Ag ratio.*	*AgCl ratio.*
4.59507	10.82441	14.38118	42.4510	31.9520
4.40117	10.36771	13.77494	42.4508	31.9506
5.71561	13.46408	17.88933	42.4508	31.9506
5.18668	12.21814	16.23430	42.4506	31.9489
5.15583	12.24555	16.13727	42.4504	31.9498
5.13108	12.08725	16.05962	42.4504	31.9502
4.85457	11.43585	15.19245	42.4505	31.9538
3.58844	8.45324	11.23091	42.4505	31.9515
5.91915	13.94377	18.52592	42.4502	31.9506
			Mean, 424506±.00006	31.9509±.00032

From the Ag ratio, P=31.006.
From the AgCl ratio, P=31.005.
The two silver ratios combine with Dumas' determinations as follows:

Dumas	42.4553±,0036
Baxter and Moore, 1	42.4509±.00012
Baxter and Moore, 1	42.4506±.00006
General mean	42.4515±.000054

The following ratios are now available for computing the atomic weight of phosphorus:

(1) $2P : P_2O_5 :: 1 : 2.28955 \pm .00032$.
(2) $3Ag : PCl_3 :: 100 : 42.4515 \pm .000054$.
(3) $3AgCl : PCl_3 :: 100 : 31.9509 \pm .00032$.
(4) $3Ag : PBr_3 :: 100 : 83.6653 \pm .00019$.
(5) $3AgBr : PBr_3 :: 100 : 48.0627 \pm .00009$.
(6) $Ag_3PO_4 : 3Ag :: 100 : 77.313 \pm .0088$.
(7) $Ag_3PO_4 : 3AgCl :: 100 : 102.704 \pm .0034$.
(8) $Ag_3PO_4 : 3AgBr :: 100 : 134.562 \pm .0012$.
(9) $5Ag : P :: 100 : 5.7322 \pm .0045$.
(10) $PH_3 = 33.931 \pm .0012$.

To reduce these we have—

Ag=107.880±.00016	Br=79.9228±.00015
Cl=35.4605±.00011	H = 1.0078±.00001

Hence,

From ratio—	
10	P=30.908±.0012
9	30.920±.0243
6	30.970±.0384
3	31.005±.0014
4	31.006±.00086
2	31.009±.00043
1	31.018±.0077
5	31.021±.00075
8	31.058±.0039
9	31.060±.0140
General mean	P=31.004±.00032

If the lowest of all these values, which has, apparently, excessive weight be rejected, the general mean of the remaining nine values becomes P=31.011±.00033.

VANADIUM.

Roscoe's determination of the atomic weight of vanadium was the first to have any scientific value. The results obtained by Berzelius [1] and by Czudnowicz [2] were unquestionably too high, the error being probably due to the presence of phosphoric acid in the vanadic acid employed. This particular impurity, as Roscoe has shown, prevents the complete reduction of V_2O_5 to V_2O_3 by means of hydrogen. All vanadium ores contain small quantities of phosphorus, which can only be detected with ammonium molybdate—a reaction unknown in Berzelius' time. Furthermore, the complete purification of vanadic acid from all traces of phosphoric acid is a matter of great difficulty, and probably never was accomplished until Roscoe undertook his researches.

In his determination of the atomic weight, Roscoe [3] studied two compounds of vanadium, namely, the pentoxide, V_2O_5, and the oxychloride, $VOCl_3$. The pentoxide, absolutely pure, was reduced to V_2O_3 by heating in hydrogen, with the following results:

7.7397 grm. V_2O_5 gave	6.3827 grm. V_2O_3.	17.533 per cent loss.	
6.5819 "	5.4296 "	17.507 "	
5.1895 "	4.2819 "	17.489 "	
5.0450 "	4.1614 "	17.515 "	
5.4296 grm. V_2O_3, reoxidized, gave	6.5814 grm. V_2O_5.	17.501 per cent difference.	
		Mean,	$17.509 \pm .005$

Hence, V = 51.381.

Upon the oxychloride, $VOCl_3$, two series of experiments were made—one volumetric, the other gravimetric. In the volumetric series the compound was titrated with solutions containing known weights of silver, which had been purified according to the methods recommended by Stas. Roscoe publishes his weighings, and gives percentages deduced from them; his figures, reduced to a common standard, make the quantities of $VOCl_3$ given in the third column proportional to 100 parts of silver. He was assisted by two analysts:

Analyst A.

$VOCl_3$	*Ag.*	*Ratio.*
2.4322	4.5525	53.425
4.6840	8.7505	53.528
4.2188	7.8807	53.533
3.9490	7.3799	53.510
.9243	1.7267	53.530
1.4330	2.6769	53.532

Analyst B.

$VOCl_3$	*Ag.*	*Ratio.*
2.8530	5.2853	53.980
2.1252	3.9535	53.755
1.4248	2.6642	53.479
		Mean, $53.586 \pm .039$

Hence, V = 51.045.

The gravimetric series, of course, fixes the ratio between $VOCl_3$ and AgCl. If we put the latter at 100 parts, the proportion of $VOCl_3$ is as given in the third column:

Analyst A.

$VOCl_3$	*AgCl.*	*Ratio.*
1.8521	4.5932	40.323
.7013	1.7303	40.531
.7486	1.8467	40.537
1.4408	3.5719	40.337
.9453	2.3399	40.399
1.6183	4.0282	40.174

[1] Poggend. Annal., 22, 14. 1831. [2] Poggend. Annal., 120, 17. 1863. [3] Journ. Chem. Soc., 6, pp. 330 and 344. 1868.

Analyst B.

$VOCl_3$	*AgCl.*	*Ratio.*
2.1936	5.4039	40.391
2.5054	6.2118	40.333
		Mean, 40.378±.028

Hence, V=51.253.

The determinations of the atomic weight of vanadium by Prandtl and Bleyer [1] appeared in two papers. Following Roscoe they analyzed vanadium oxychloride, and also studied the reduction of the pentoxide by hydrogen. In their first paper the following figures, with vacuum weights are given:

Series 1.

$VOCl_3$.	*AgCl.*	*Ratio.*
5.47218	13.54724	40.393
5.85234	14.50771	40.346
3.23175	8.00636	40.365
5.24732	13.01359	40.322
3.56589	8.83375	40.367
		Mean, 40.359±.0080

Hence, V=51.171.

Series 2.

$VOCl_3$.	*AgCl.*	*Ratio.*
4.91432	12.18494	40.331
3.64470	9.04685	40.286
4.96088	12.30438	40.318
6.46766	16.04232	40.315
4.33158	10.74624	40.308
4.05060	10.04498	40.325
		Mean, 40.314±.0043

Hence, V=50.978.

Four additional determinations given in Prandtl and Bleyer's second paper I cite here as series 3.

Series 3.

$VOCl_3$.	*AgCl.*	*Ratio.*
5.53988	13.73492	40.334
7.77585	19.26836	40.356
8.41904	20.86554	40.343
10.66137	26.42699	40.343
		Mean, 40.345±.0037

Hence, V=51.111.

As in Roscoe's determinations vanadium pentoxide was reduced to trioxide by heating in a current of hydrogen. The following figures are given:

V_2O_5	V_2O_3	*Per cent lost.*
9.11431	7.51639	17.532
9.85727	8.13127	17.510
8.70923	7.18456	17.506
12.26426	10.11721	17.507
		Mean, 17.514±.0041

Hence, V=51.357.

Combining this series with that of Roscoe, the general mean becomes 17.5117±.0034.

An entirely different method of determining the atomic weight of vanadium was adopted by McAdam.[2] Sodium metavanadate was heated in a stream of gaseous hydrochloric acid,

[1] Zeitsch. anorg. Chem., 65, 152. 1909. 67, 257. 1910. See also the academic dissertation by Bleyer, München, 1910.

[2] Journ. Amer. Chem. Soc., 32, 1603. 1910.

the vanadium was thus volatilized as chloride, and sodium chloric remained behind. The following data, with vacuum weights, were thus obtained:

$NaVO_3$.	$NaCl$.	Per cent $NaCl$.
4.8564	2.3277	47.931
5.6404	2.7033	47.927
4.4263	2.1220	47.941
5.7805	2.7710	47.937
9.4902	4.5478	47.921
		Mean, 47.931±.0032

Hence, V=50.971.

The determinations by Briscoe and Little[1] were based on analyses of the oxychloride, with all the precautions to ensure accuracy which have been recognized in recent times. Two sets of determinations are given, with vacuum weights, as follows: Two analyses, rejected by the authors, are omitted here.

Series 1.

$VOCl_3$.	Ag.	Ratio.
3.98162	7.43451	53.556
5.63804	10.52736	53.556
3.88228	7.24884	53.557
3.28485	6.13377	53.554
3.45920	6.45900	53.556
3.17088	5.92089	53.554
3.63990	6.79670	53.554
		Mean, 53.555±.00036

Hence, V=50.944.

Series 2.

$VOCl_3$.	AgCl.	Ratio.
4.42279	10.97187	40.310
2.62557	6.51459	40.307
		Mean, 40.3085±.0010

Hence, V=50.941.

These $VOCl_3$ ratios can now be combined with the previous determinations thus:

Ratio 3Ag : $VOCl_3$: : 100 : x.

Roscoe	53.586±.039
Briscoe and Little	53.555±.00036
General mean	53.555±.00035

Ratio 3AgCl: $VOCl_3$: : 100: x.

Roscoe	40.378 ±.028
Prandtl and Bleyer 1	40.359 ±.0080
Prandtl and Bleyer 2	40.314 ±.0043
Prandtl and Bleyer 3	40.345 ±.0037
Briscoe and Little	40.3085±.0010
General mean	40.3119±.00094

There are now four ratios relative to the atomic weight of vanadium. They are—

(1) $V_2O_5 : 2O :: 100 : 17.5117 = .0034$.
(2) $3Ag : VOCl_3 :: 100 : 53.555 \pm .00035$.
(3) $3AgCl : VOCl_3 :: 100 : 40.3119 \pm .00094$.
(4) $NaVO_3 : NaCl :: 100 : 47.931 \pm .0032$.

Reducing these with Ag=107.880±.00016; Cl=35.4605±.00011; and Na=23.0029±.00012, we have—

From ratio—	
2	V=50.944±.00043
3	50.969±.0013
4	50.971±.0030
1	51.367±.0299
General mean	50.947±.0004

[1] Journ. Chem. Soc., 105, 1310. 1914.

The determinations by Briscoe and Little dominate the entire combination. The value derived from vanadium oxide practically vanishes.

ARSENIC.

For the determination of the atomic weight of arsenic five compounds have been studied—the chloride, the trioxide, and three arsenates. The bromide may also be considered, since it was analyzed by Wallace in order to establish the atomic weight of bromine. His series, in the light of more recent knowledge, may properly be inverted, and applied to the determination of arsenic.

In 1826 Berzelius[1] heated arsenic trioxide with sulphur in such a way that only SO_2 could escape. 2.203 grammes of As_2O_3, thus treated, gave a loss of 1.069 of SO_2. Hence, As = 75.02.

In 1845 Pelouze[2] applied his method of titration with known quantities of pure silver to the analysis of trichloride of arsenic, $AsCl_3$. Using the old Berzelian atomic weights, and putting Ag = 1349.01 and Cl = 443.2, he found in three experiments for As the values 937.9, 937.1, and 937.4. Hence, 100 parts of silver balance the following quantities of $AsCl_3$:

56.029
56.009
56.016

Mean, 56.018 ± .004

Hence, As = 74.91.

Later, the same method was employed by Dumas,[3] whose weighings, reduced to the foregoing standard, give the following results:

$AsCl_3$.	*Ag.*	*Ratio.*
4.298	7.673	56.015
5.535	9.880	56.022
7.660	18.686	55.970
4.680	8.358	55.993

Mean, 56.000 ± .008

Hence, As = 74.86.

The two series of Pelouze and Dumas, combined, give a general mean of 56.014 ± .0035, as the amount of $AsCl_3$ equivalent to 100 parts of silver. Hence, As = 74.91, a value closely agreeing with that deduced from the single experiment of Berzelius.

The same process of titration with silver was applied by Wallace[4] to the analysis of arsenic tribromide, $AsBr_3$. This compound was repeatedly distilled to insure purity, and was well crystallized. His weighings show that the quantities of bromide given in the third column are proportional to 100 parts of silver:

$AsBr_3$.	*Ag.*	*Ratio.*
8.3246	8.58	97.023
4.4368	4.573	97.022
5.098	5.257	96.970

Mean, 97.005 ± .012

Hence, As = 74.18. Why this value should be so much lower than that from the chloride is unexplained.

The volumetric work done by Kessler,[5] for the purpose of establishing the atomic weights of chromium and of arsenic, is described in the chromium chapter. In that investigation the amount of potassium dichromate required to oxidize 100 parts of As_2O_3 to As_2O_5 was determined and compared with the quantity of potassium chlorate necessary to produce the same effect. From the molecular weight of $KClO_3$, that of $K_2Cr_2O_7$ was then calculable.

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[1] Poggend. Annalen, 8, 1.
[2] Compt. Rend., 20, 1047.
[3] Ann. Chim. Phys. (3), 55, 174. 1859.
[4] Phil. Mag. (4), 18, 270.
[5] Poggend. Annal., 95, 204. 1855. Also 113, 134. 1861.

From the same figures, the molecular weights of $KClO_3$ and of $K_2Cr_2O_7$ being both known, that of As_2O_3 may be easily determined. The quantities of the other compounds proportional to 100 parts of As_2O_3 are as follows:

$K_2Cr_2O_7$.	$KClO_3$.
98.95	41.156
98.94	41.116
99.17	41.200
98.98	41.255
99.08	41.201
99.15	41.086
	41.199
Mean, 99.045±.028	41.224
	41.161
	41.193
	41.149
	41.126
	Mean, 41.172±.009

Another series with the dichromate gave the following figures:

99.08
99.06
99.10
98.97
98.97
Mean, 99.036±.019
Previous series, 99.045±.028
General mean, 99.039±.016

Other defective series are given to illustrate the partial oxidation of the As_2O_3 by the action of the air. From Kessler's data we get two values for the atomic weight of As, thus:

From $KClO_3$ series.....As=75.224
From $K_2Cr_2O_7$ series.....As=75.029

The determinations made by Hibbs [1] are based upon an altogether different process from any of the preceding measurements. Sodium pyroarsenate was heated in gaseous hydrochloric acid, yielding sodium chloride. The latter was perfectly white, completely soluble in water, unfused, and absolutely free from arsenic. The vacuum weights are subjoined, with a column giving the percentage of chloride obtained from the pyroarsenate.

$Na_4As_2O_7$.	$NaCl$.	*Percentage.*
0.02177	0.01439	66.100
.04713	.03115	66.094
.05795	.03830	66.091
.40801	.26981	66.128
.50466	.33345	66.092
.77538	.51249	66.095
.82897	.54791	66.095
1.19124	.78731	66.092
1.67545	1.10732	66.091
3.22637	2.13267	66.101
		Mean, 66.098±.0030

Hence, As=74.893.

[1] Doctoral thesis, University of Pennsylvania, 1896. Work done under the direction of Professor E. F. Smith. In the fifth experiment the weight of NaCl is printed 0.33045. This is evidently a misprint, which I have corrected by comparison with the other data. The rejection of this experiment would not affect the final result appreciably.

The determinations by Ebaugh [1] are analogous to those of Hibbs. First, silver arsenate was converted into silver chloride by heating in gaseous hydrochloric acid, and the chloride was afterwards reduced to metal in a stream of hydrogen. The data obtained are as follows:

Ag_2AsO_4.	$AgCl$.	Ag.	Per cent $AgCl$.	Per cent. Ag.
0.23182	0.21547	0.162175	92.947	69.957
.47996	.44615	.33583	92.956	69.970
.52521	.48820	.367525	92.953	69.977
.80173	.74517	.56099	92.945	69.972
.94782	.°8083	.66318	92.932	69.969
1.02047	.94830	.71400	92.928	69.968
1.03558	.96258	.....	92.951	.....
1.05462	.98014	.73771	92.938	69.950
			Mean, 92.944±.0025	69.966±.0024

From Ag series, As = 74.928.
From AgCl series, As = 75.027.
A similar series of experiments with lead arsenate gave the subjoined figures:

$Pb_3(AsO_4)_2$.	$PbCl_2$.	Per cent $PbCl_2$
0.38152	0.35381	92.737
.436197	.40449	92.731
.57218	.53065	92.742
.60085	.55717	92.730
.74123	.68736	92.732
.77107	.71494	92.721
.88282	.81858	92.723
.97779	.90674	92.734
		Mean, 92.731±.0019

Hence As = 75.077.
Lead arsenate was also transformed into lead bromide, by heating in a stream of hydrobromic acid:

$Pb_3(AsO_4)_2$.	$PbBr_2$.	Per cent $PbBr_2$.
0.59704	0.73092	122.424
.61712	.75567	122.451
.65799	.80569	122.447
		Mean, 122.441±.0076

Hence As = 74.877.
All of Ebaugh's weights are reduced to a vacuum.
Silver arsenate was also chosen by Baxter and Coffin [2] for their determinations of the atomic weight of arsenic. In some experiments Ebaugh's method of heating in gaseous hydrochloric acid was adopted; in others the arsenate was dissolved in nitric acid, and the silver then precipitated as chloride or bromide. Corrections were applied, not only for weighing in air, but also for traces of moisture in the initial substance. Different samples of the arsenate were prepared, which gave slightly varying results for the atomic weight, and the determinations, for that reason, fall into two groups. In series 1 and 2, which may be treated as one here, the first five determinations were made by Ebaugh's method, and the last two by solution and precipitation. The figures thus obtained are as follows:

Ag_3AsO_4.	$AgCl$.	Ratio.
3.17276	2.94922	92.9544
2.65042	2.46367	92.9539
3.51128	3.26396	92.9564
5.83614	5.42503	92.9558
5.72252	5.31947	92.9568
4.59149	4.26796	92.9537
3.38270	3.14436	92.9542
		Mean, 92.9550±.00036

Hence As = 74.973.

[1] Doctoral thesis, University of Pennsylvania, 1901.
[2] Journ. Amer. Chem. Soc., 31, 297. 1909.

Series 4 and 5, with silver arsenate of different origin from that previously used, gave the subjoined figures. Only the last experiment was conducted by the precipitation method:

Ag_3AsO_4.	$AgCl$.	Ratio.
4. 67268	4. 34389	92. 9636
7. 71882	7. 17597	92. 9672
5. 28049	4. 90908	92. 9664
4. 25346	3. 95424	92. 9652
3. 47340	3. 22893	92. 9616
5. 17269	4. 80879	92. 9650
4. 10766	3. 81858	92. 9624
5. 47133	5. 08643	92. 9646
		Mean, 92. 9681±. 00044

Hence As = 74.907.

These series combine with Ebaugh's thus:

Ebaugh	92. 944 ±. 0025
Baxter and Coffin, 1	92. 9550±. 00036
Baxter and Coffin, 2	92. 9681±. 00044
General mean	92. 9614±. 00028

Baxter and Coffin also determined the ratio between silver arsenate and silver bromide by the solution and precipitation method. Here again two series of analyses are given, numbered 3 and 6, representing different preparations of the arsenate. The two series are as follows:

Series 3.

Ag_3AsO_4.	$AgBr$.	Ratio.
8. 75751	10. 66553	121. 787
6. 76988	8. 24545	121. 796
5. 19424	6. 32590	121. 787
5. 33914	6. 50258	121. 791
8. 24054	10. 03552	121. 782
7. 57962	9. 23147	121. 793
6. 05230	7. 37106	121. 789
		Mean, 121. 789±. 0016

Series 6.

Ag_3AsO_4.	$AgBr$.	Ratio.
4. 96261	6. 04440	121. 7988
5. 31743	6. 47658	121. 7991
4. 46882	5. 44300	121. 7995
4. 16702	5. 07539	121. 7990
		Mean, 121. 7991±. 00015

In the last mean the probable error is so low as to give it inordinate weight, especially as Baxter and Coffin suspect the presence of basic impurities in the arsenate. It is better, therefore, to treat both series as one, giving in mean $Ag_3AsO_4 : 3AgBr :: 100 : 121.793 \pm .0012$. Hence As = 74.955.

There are now the following ratios from which to compute the atomic weight of arsenic. The single determination by Berzelius has been arbitrarily assigned equal weight with that of Wallace's series:

(1) $2As_2O_3 : 3SO_2 :: 100 : 48.525 \pm .012$.
(2) $3Ag : AsCl_3 :: 100 : 56.014 \pm .0035$.
(3) $3Ag : AsBr_3 :: 100 : 97.005 \pm .012$.
(4) $3As_2O_3 : 2K_2Cr_2O_7 :: 100 : 99.039 \pm .016$.
(5) $3As_2O_3 : 2KClO_3 :: 100 : 41.172 \pm .009$.
(6) $Na_4As_2O_7 : 4NaCl :: 100 : 66.098 \pm .0030$.

(7) $Ag_3AsO_4 : 3Ag :: 100 : 69.966 \pm .0024$.
(8) $Ag_3AsO_4 : 3AgCl :: 100 : 92.9614 \pm .00028$.
(9) $Ag_3AsO_4 : 3AgBr :: 100 : 121.793 \pm .0012$.
(10) $Pb_3As_2O_8 : 3PbCl_2 :: 100 : 92.731 \pm .0019$.
(11) $Pb_3As_2O_8 : 3PbBr_2 :: 100 : 122.441 \pm .0076$.

To reduce these ratios we have—

Ag=107. 880±. 00016	Na=23. 0029±. 00012
Cl=35. 4605±. 00011	K=39. 0975±. 00011
Br=79. 9228±. 00015	Cr=52. 019±. 0013
S=32. 0650±. 00012	Pb=207. 102±. 00062

Hence,

From ratio—	
3	As=74. 179±. 0389
11	74. 877±. 0234
6	74. 893±. 0080
2	74. 901±. 0113
7	74. 928±. 0160
8	74. 941±. 0015
9	74. 955±. 0026
1	75. 019±. 0077
4	75. 029±. 0157
10	75. 077±. 0062
5	75. 224±. 0217
General mean	As=74. 956±. 0012

This final mean is practically identical with the value derived from the analyses of silver arsenate by Baxter and Coffin.

ANTIMONY.

After some earlier, unsatisfactory determinations, Berzelius,[1] in 1826, published his final estimation of the atomic weight of antimony. He oxidized the metal by means of nitric acid, and found that 100 parts of antimony gave 124.8 of Sb_2O_4. Hence Sb = 129.03. The value 129 remained in general acceptance until 1855, when Kessler,[2] by special volumetric methods, showed that it was certainly much too high. Kessler's results will be considered more fully further along, in connection with a later paper; for present purposes a brief statement of his earlier conclusions will suffice. Antimony and various compounds of antimony were oxidized partly by potassium dichromate and partly by potassium chlorate, and from the amounts of oxidizing agent required the atomic weight in question was deduced:

By oxidation of Sb_2O_3 from 100 parts of Sb	Sb=123. 84
By oxidation of Sb with $K_2Cr_2O_7$	" =123. 61
By oxidation of Sb with $KClO_3+K_2Cr_2O_7$	" =123. 72
By oxidation of Sb_2O_3 with $KClO_3+K_2Cr_2O_7$	" =123. 80
By oxidation of Sb_2S_3 with $K_2Cr_2O_7$	" =123. 58
By oxidation of tartar emetic	" =119. 80

The figures given are those calculated by Kessler himself. A recalculation with our newer atomic weights for O, K, Cl, Cr, S and C would yield slightly different values. It will be seen that five of the estimates agree closely, while one diverges widely from the others. It will be shown hereafter that the concordant values are all vitiated by constant errors, and that the exceptional figure is also worthless.

Shortly after the appearance of Kessler's first paper, Schneider[3] published some results obtained by the reduction of antimony sulphide in hydrogen. The material chosen was a very pure stibnite from Arnsberg, of which the gangue was only quartz. This was corrected for, and corrections were also applied for traces of undecomposed sulphide carried off mechanically by the gas stream, and for traces of sulphur retained by the reduced antimony. The latter sulphur

[1] Poggend. Annalen, 8, 1. [2] Poggend. Annalen, 95, 215. [3] Poggend. Annalen, 98, 293. 1856. Preliminary note in Bd. 97.

was estimated as barium sulphate. From 3.2 to 10.6 grammes of material were taken in each experiment. The final percentages of S in Sb_2S_3 were as follows:

28.559	28.532
28.557	28.485
28.501	28.492
28.554	28.481

Mean, 28.520±.008

Hence, Sb = 120.55.

Immediately after the appearance of Schneider's memoir, Rose [1] published the result of a single analysis of antimony trichloride, previously made under his supervision by Weber. This analysis, if Cl = 35.5, makes Sb = 120.7, a value of no great weight, but in a measure confirmatory of that obtained by Schneider.

The next research upon the atomic weight of antimony was that of Dexter,[2] published in 1857. This chemist, having tried to determine the amount of gold precipitable by a knowu weight of antimony, and having obtained discordant results, finally resorted to the original method of Berzelius. Antimony, purified with extreme care, was oxidized by nitric acid, and the gain in weight was determined. From 1.5 to 3.3 grammes of metal were used in each experiment. The reduction of the weights to a vacuum standard was neglected as being superfluous. From the data obtained, we get the following percentages of Sb in Sb_2O_4:

79.268	79.260
79.272	79.286
79.255	79.274
79.266	79.232
79.253	79.395
79.271	79.379
79.264	

Mean, 79.283±.009

Hence, Sb = 122.46.

The determinations of Dumas [3] were published in 1859. This chemist sought to fix the ratio between silver and antimonious chloride, and obtained results for the atomic weight of antimony quite near to those of Dexter. The $SbCl_3$ was prepared by the action of dry chlorine upon pure antimony; it is was distilled several times over antimony powder, and it seemed to be perfectly pure. Known weights of this preparation were added to solutions of tartaric acid in water, and the silver chloride was precipitated without previous removal of the antimony. Here, as Cooke has since shown, is a possible source of error, for under such circumstances the crystalline argento-antimonious tartrate may also be thrown down and contaminate the chloride of silver. But be that as it may, Dumas's weighings, reduced to a common standard, give as proportional to 100 parts of silver, the quantities of $SbCl_3$ which are stated in the third of the following columns:

$SbCl_3$.	*Ag.*	*Ratio.*
1.876	2.660	70.526
4.336	6.148	70.527
5.065	7.175	70.592
3.475	4.930	70.487
3.767	5.350	70.411
5.910	8.393	70.416
4.828	6.836	70.626

Mean, 70.512±.021

Hence, Sb = 121.82.

In 1861 Kessler's second paper [4] relative to the atomic weight of antimony appeared. Kessler's methods were somewhat complicated, and for full details the original memoirs must be consulted. A standard solution of potassium dichromate was prepared, containing 6.1466 grammes to the liter. With this, solutions containing known quantities of antimony or of antimony compounds were titrated, the end reaction being adjusted with a standard solution of ferrous chloride. In some cases the titration was preceded by the addition of a definite weight of

[1] Poggend. Annalen, 98, 455. 1856.
[2] Poggend. Annalen, 100, 363. 1857.
[3] Ann. Chim. Phys. (3), 55, 175.
[4] Poggend. Annalen, 113, 145. 1861.

potassium chlorate, insufficient for complete oxidation; the dichromate then served to finish the reaction. The object in view was to determine the amount of oxidizing agent, and therefore of oxygen, necessary for the conversion of known quantities of antimonious into antimonic compounds.

In the later paper Kessler refers to his earlier work, and shows that the values then found for antimony were all too high, except in the case of the series made with tartar emetic. That series he merely states, and subsequently ignores, evidently believing it to be unworthy of further consideration. For the remaining series he points out the sources of error. These need not be rediscussed here, as the discussion would have no value for present purposes; suffice it to say that in the series representing the oxidation of Sb_2O_3 with the dichromate and chlorate, the material used was found to be impure. Upon estimating the impurity and correcting for it, the earlier value of Sb = 123.80 becomes Sb = 122.36, according to Kessler's calculations.

In the paper now under consideration four series of results are given. The first represents experiments made upon a pure antimony trioxide which had been sublimed, and which consisted of shining colorless needles. This was dissolved, together with some potassium chlorate, in hydrochloric acid, and titrated with dichromate solution. Six experiments were made, but Kessler rejects the first and second as untrustworthy. The data for the others are as follows:

Sb_2O_3.	*$KClO_3$.*	*$K_2Cr_2O_7$ sol. in cc.*
1. 7888	0. 4527	19. 2
1. 6523	. 4506	3. 9
3. 2998	. 8806	16. 5
1. 3438	. 3492	10. 2

From these figures Kessler deduces Sb = 122.16.

These data, reduced to a common standard, give the following quantities of oxygen needed to oxidize 100 parts of Sb_2O_3 to Sb_2O_5. Each cubic centimetre of the $K_2Cr_2O_7$ solution corresponds to one milligramme of O :

10. 985	10. 951
10. 939	10. 936

Mean, 10. 953 ± . 0075

Hence, Sb = 122.08.

In the second series of experiments pure antimony was dissolved in hydrochloric acid with the aid of an unweighed quantity of potassium chlorate. The solution, containing both antimonious and antimonic compounds, was then reduced entirely to the antimonious condition by means of stannous chloride. The excess of the latter was corrected with a strong hydrochloric acid solution of mercuric chloride, then, after diluting and filtering, a weighed quantity of potassium chlorate was added, and the titration with dichromate was performed as usual. Calculated as above, the percentages of oxygen given in the last column correspond to 100 parts of antimony :

Sb.	*$KClO_3$.*	*$K_2Cr_2O_7$ sol. cc.*	*Per cent O.*
1. 636	0. 5000	18. 3	13. 088
3. 0825	. 9500	30. 2	13. 050
4. 5652	1. 4106	45. 5	13. 098
			Mean, 13. 079 ± . 0096

Hence, Sb = 122.33.

The third and fourth series of experiments were made with pure antimony trichloride, $SbCl_3$, prepared by the action of mercuric chloride upon metallic antimony. This preparation, in the third series, was dissolved in hydrochloric acid, and titrated. In one experiment solid $K_2Cr_2O_7$ in weighed amount was added before titration; in the other two estimations $KClO_3$ was taken as usual. The third column gives the percentages of oxygen corresponding to 100 parts of $SbCl_3$:

							Per cent O.
1. 8576 grm.	$SbCl_3$	needed	. 5967 grm.	$K_2Cr_2O_7$	and 33. 4 cc.	sol.	7. 0338
1. 9118	"		. 3019 "	$KClO_3$	" 16. 2	"	7. 0321
4. 1235	"		. 6801 "	$KClO_3$	" 23. 2	"	7. 0222
							Mean, 7. 0294 ± . 0024

Hence, Sb = 121.24.

The fourth set of experiments was gravimetric. The solution of $SbCl_3$, mixed with tartaric acid, was first precipitated by hydrogen sulphide, in order to remove the antimony. The excess of H_2S was corrected by copper sulphate, and then the chlorine was estimated as silver chloride in the ordinary manner. 100 parts of AgCl correspond to the amounts of $SbCl_3$ given in the third column:

$SbCl_3$.	*AgCl.*	*Ratio.*
1. 8662	3. 483	53. 580
1. 6832	3. 141	53. 588
2. 7437	5. 1115	53. 677
2. 6798	5. 0025	53. 569
5. 047	9. 411	53. 629
3. 8975	7. 2585	53. 696
		Mean, 53. 623 ± . 015

The volumetric series with $SbCl_3$ gave Kessler values for Sb ranging from 121.16 to 121.47. The gravimetric series, on the other hand, yielded results from Sb = 124.12 to 124.67. This discrepancy Kessler rightly attributes to the presence of oxygen in the chloride; and, ingeniously correcting for this error, he deduces from both sets combined the value of Sb = 122.37.

The several mean results for antimony agree so fairly with each other, and with the values obtained by Dexter and Dumas, that we can not wonder that Kessler felt satisfied of their general correctness, and of the inaccuracy of the figures published by Schneider. Still, the old series of data obtained by the titration of tartar emetic with dichromate contained no evident errors, and was not accounted for. This series,[1] if we reduce all of Kessler's figures to a single common standard, gives a ratio between $K_2Cr_2O_7$ and $C_4H_4KSbO_7.\frac{1}{2}H_2O$. 100 parts of the former will oxidize of the latter :

336. 64	337. 93
338. 01	338. 59
336. 83	335. 79

Mean, 337. 30 ± . 29

From this Sb = 118.67.

The newer atomic weights found in other chapters of this work will be applied to the discussion of all these series further along. It may, however, be properly noted at this point that the probable errors assigned to the percentages of oxygen in three of Kessler's series are too low. These percentages are calculated from the quantities of $KClO_3$ involved in the several reactions, and their probable errors should be increased with reference to the probable error of the molecular weight of that salt. The necessary calculations would be more laborious than the importance of the figures would warrant, and accordingly, in computing the final general mean for antimony, Kessler's figures will receive somewhat higher weight than they are legitimately entitled to.

Naturally, the concordant results of Dexter, Kessler and Dumas led to the general acceptance of the value of 122 for antimony as against the lower figure, 120, of Schneider. Still, in 1871, Unger [2] published the results of a single analysis of Schlippe's salt, $Na_3SbS_4.9H_2O$. This analysis gave Sb = 119.76, if S = 32 and Na = 23, but no great weight could be attached to the determination. It served, nevertheless, to show that the controversy over the atomic weight of antimony was not finally settled.

More than ten years after the appearance of Kessler's second paper the subject of the atomic weight of antimony was again taken up, this time by Professor Cooke. His results appeared in the autumn of 1877 [3] and were conclusive in favor of the lower value, approximately 120. For full details the original memoir must be consulted; only a few of the leading points can be cited here.

Schneider analyzed a sulphide of antimony which was already formed. Cooke, reversing the method, effected the synthesis of this compound. Known weights of pure antimony were dissolved in hydrochloric acid containing a little nitric acid. In this solution weighed balls of antimony were boiled until the liquid became colorless; subsequently the weight of metal

[1] Poggend. Annalen, 95, 217. [2] Archiv der Pharmacie, 197, 194. Quoted by Cooke. [3] Proc. Amer. Acad., 5, 13.

lost by the balls was ascertained. To the solution, which now contained only antimonious compounds, tartaric acid was added, and then, with a supersaturated aqueous sulphhydric acid, antimony trisulphide was precipitated. The precipitate was collected by an ingenious process of reverse filtration, converted into the black modification by drying at 210°, and weighed. After weighing, the Sb_2S_3 was dissolved in hydrochloric acid, leaving a carbonaceous residue unacted upon. This was carefully estimated and corrected for. About two grammes of antimony were taken in each experiment and 13 syntheses were performed. In two of these, however, the antimony trisulphide was weighed only in the red modification, and the results were uncorrected by conversion into the black variety and estimation of the carbonaceous residue. In fact, every such conversion and correction was preceded by a weighing of the red modification of the Sb_2S_3. The mean result of these weighings, if S = 32, gave Sb = 119.994. The mean result of the corrected syntheses gave Sb = 120.295. In these eleven experiments the following percentages of S in Sb_2S_3 were established:

28.57	28.50
28.60	28.49
28.57	28.58
28.43	28.50
28.42	28.51
28.53	

Mean, 28.5182 ± .0120

Hence, Sb = 120.58.

These results, confirmatory of the work of Schneider, were presented to the American Academy in 1876. Still, before publication, Cooke thought it best to repeat the work of Dumas, in order to detect the cause of the old discrepancy between the values Sb = 120 and Sb = 122. Accordingly, various samples of antimony trichloride were taken, and purified by repeated distillations. The final distillate was further subjected to several recrystallizations from the fused state; or, in one case, from a saturated solution in bisulphide of carbon. The portions analyzed were dissolved in concentrated aqueous tartaric acid, and precipitated by silver nitrate, many precautions being observed. The silver chloride was collected by reverse filtration, and dried at temperatures from 110° to 120°. In one experiment the antimony was first removed by H_2S. Seventeen experiments were made as follows. If we reduce to a common standard, Cooke's analyses give, as proportional to 100 parts of AgCl, the quantities of $SbCl_3$ stated in the third column:

$SbCl_3$.	*AgCl.*	*Ratio.*
1.5974	3.0124	53.028
1.2533	2.3620	53.061
.8876	1.6754	52.978
.8336	1.5674	53.184
.5326	1.0021	53.148
.7270	1.3691	53.101
1.2679	2.3883	53.088
1.9422	3.6646	52.999
1.7702	3.3384	53.025
2.5030	4.7184	53.048
2.1450	4.0410	53.081
1.7697	3.3281	53.175
2.3435	4.4157	53.072
1.3686	2.5813	53.020
1.8638	3.5146	53.030
2.0300	3.8282	53.028
2.4450	4.6086	53.053

Mean, 53.066 ± .0096

Hence, Sb = 121.81.

This mean may be combined with that of Kessler's series, as follows:

Kessler	53.623 ± .015
Cooke	53.066 ± .0096
General mean	53.2311 ± .008

The results thus obtained with SbCl3, confirmed Dumas' determination of the atomic weight of antimony as remarkably as the syntheses of Sb_2S_3 had sustained the work of Schneider. Evidently, in one or the other series a constant error must be hidden, and much time was spent by Cooke in searching for it. It was eventually found that the chloride of antimony invariably contained traces of oxychloride, an impurity which tended to increase the apparent atomic weight of the metal under consideration. It was also found, in the course of the investigation, that hydrochloric acid solutions of antimonious compounds oxidize in the air during boiling as rapidly as ferrous compounds, a fact which explains the high values for antimony found by Kessler.[1]

In order to render "assurance doubly sure," Cooke also undertook the analysis of the bromide and the iodide of antimony. The bromide, $SbBr_3$, was prepared by adding the finely powdered metal to a solution of bromine in carbon disulphide. It was purified by repeated distillation over pulverized antimony, and by several recrystallizations from bisulphide of carbon. The bromine determinations resemble those of chlorine. Reduced to a common standard, the 15 analyses give the subjoined quantities of $SbBr_3$ proportional to 100 parts of silver bromide:

$SbBr_3$.	*AgBr.*	*Ratio.*
1.8621	2.9216	63.736
.9856	1.5422	63.909
1.8650	2.9268	63.721
1.5330	2.4030	63.795
1.3689	2.1445	63.833
1.2124	1.8991	63.841
.9417	1.4749	63.848
2.5404	3.9755	63.901
1.5269	2.3905	63.874
1.8604	2.9180	63.756
1.7298	2.7083	63.870
3.2838	5.1398	63.890
2.3589	3.6959	63.825
1.3323	2.0863	63.859
2.6974	4.2285	63.791
		Mean, 63.830±.008

Hence, Sb = 119.86.

The iodide of antimony was prepared like the bromide, and analyzed in the same way. At first discordant results were obtained, due to the presence of oxyiodide in the iodide studied. The impurity, however, was removed by subliming the iodide in an atmosphere of dry carbon dioxide. With this purer material seven estimations of iodine were made. Reduced to a uniform standard, Cooke's weighings give the following quantities of SbI_3 proportional to 100 parts of silver iodide:

SbI_3.	*AgI.*	*Ratio.*
1.1877	1.6727	71.005
.4610	.6497	70.956
3.2527	4.5716	71.150
1.8068	2.5389	71.165
1.5970	2.2456	71.117
2.3201	3.2645	71.071
.3496	.4927	70.956
		Mean, 71.060±.023

Hence, Sb = 119.78.

Although Cooke's work was practically conclusive, as between the rival values for antimony, his results were severely criticized by Kessler,[2] who evidently had read Cooke's paper in a very careless way. On the other hand, Schneider published in Poggendorff's Annalen a friendly review of the new determinations, which so well vindicated his own accuracy. In

[1] In Amer. Journ. Sci. (3), 21, 220, Cooke pointed out the errors due to the solubility of silver chloride, and gave two series of analyses of $SbCl_3$ to illustrate their magnitude.

[2] Berichte Deutsch. chem. Gesell. ,12, 1044. 1879.

reply to Kessler, Cooke undertook still another series of experiments with antimony bromide,[1] and obtained absolute confirmation of his previous results. To a solution of antimony bromide was added a solution containing a known weight of silver not quite sufficient to precipitate all the bromine. The excess of the latter was estimated by titration with a normal silver solution. Five analyses gave values for antimony ranging from 119.98 to 120.02, when Ag = 108 and Br = 80. Reduced to a common standard, the weights obtained gave the amounts of $SbBr_3$ stated in the third column as proportional to 100 parts of silver:

$SbBr_3$.	*Ag.*	*Ratio.*
2.5032	2.2528	111.115
2.0567	1.8509	111.119
2.6512	2.3860	111.115
3.3053	2.9749	111.106
2.7495	2.4745	111.113
		Mean, 111.114±.0014

Hence, Sb = 119.84.

Schneider,[2] also, in order to more fully answer Kessler's objections, repeated his work upon the Arnsberg stibnite. This he reduced in hydrogen as before, correcting scrupulously for impurities. The following percentages of sulphur were found:

28.546
28.534
28.542
Mean, 28.541±.0024

Hence, Sb = 120.42.

These figures confirm his old results, and may be fairly combined with them and with the percentages found by Cooke, as follows:

Schneider, early series	28.520 ±.008
Schneider, late series	28.541 ±.0024
Cooke	28.5182±.0120
General mean	28.5385±.0023

In 1881 Pfeifer[3] determined electrolytically the direct ratios between silver and antimony, and copper and antimony. With copper the following data were obtained:

Sb.	*Cu.*	*3Cu : 2Sb : : 100 : x.*
1.412	1.1008	128.270
1.902	1.4832	128.236
3.367	2.6249	128.272
		Mean, 128.259±.0077

Hence, Sb = 122.27.

With silver he found—

Sb.	*Ag.*	*3Ag : Sb : : 100 : x.*
5.925	15.774	37.562
6.429	17.109	37.577
10.116	26.972	37.506
4.865	13.014	37.383
4.390	11.697	37.531
9.587	25.611	37.433
4.525	12.097	37.406
		Mean, 37.485±.0198

Hence, Sb = 121.32.

The latter ratio was determined by Popper,[4] several years afterwards. The two metals were precipitated simultaneously by the same current; and in some experiments two portions

[1] Amer. Journ. Sci., May, 1880. Berichte, 13, 951.
[2] Journ. prakt. Chem. (2), 22, 131.
[3] Ann. Chem. Pharm., 209, 161.
[4] Ann. Chem., 233, 153.

of antimony were thrown down against one of silver. These are indicated in the subjoined table by suitable bracketing, and the ratio is given in the third column:

Sb.	*Ag.*	*Ratio.*
1.4856	3.9655	37.463
1.4788		37.292
2.0120	5.3649	37.503
2.0074		37.417
3.8882	10.3740	37.480
3.8903		37.500
4.1893	11.1847	37.455
4.1885		37.447
4.2710	11.3868	37.507
4.2752		37.545
5.6860	15.1786	37.460
5.6901		37.487
4.4117	11.8014	37.383
4.9999	13.3965	37.322
5.2409	14.0679	37.250
		Mean, 37.434±.0149
		Pfeifer found, 37.485±.0198
		General mean, 37.452±.0119

Popper's figures give in mean Sb = 121.15.

The recent investigations by Cohen and Strengers [1] seem to prove that these electrolytic determinations are worthless. They effected the simultaneous precipitation of silver and antimony, using solutions of $SbCl_3$, and found that the apparent atomic weight of antimony increased with the concentration of the solutions. They give the results of 24 determinations, with full details, but only the end results need be cited here:

With 2.3 grm. $SbCl_3$ in 100 cc. of solution, Sb=120.84 to 120.87
" 83.3 " Sb=121.81 to 121.92

These values are calculated with old values for Cl and Ag, but they show the failure of the process to yield trustworthy figures. In any final discussion of the atomic weight of antimony, therefore, the work of Pfeifer and Popper must be disregarded.

The work done by Bongartz [2] in 1883 was quite different from any of the determinations which had preceded it. Carefully purified antimony was weighed as such, and then dissolved in a concentrated solution of potassium sulphide. From this, after strong dilution, antimony trisulphide was thrown down by means of dilute sulphuric acid. After thorough washing, this sulphide was oxidized by hydrogen peroxide, by Classen's method, and the sulphur in it was weighed as barium sulphate. The ratio measured, therefore, was $2Sb : 3BaSO_4$, and the data were as follows. The $BaSO_4$ equivalent to 100 parts of Sb is the ratio stated:

Sb taken.	*$BaSO_4$ found.*	*Ratio.*
1.4921	4.3325	290.362
.6132	1.7807	290.394
.5388	1.5655	290.553
1.2118	3.5205	290.518
.9570	2.7800	290.491
.6487	1.8855	290.349
.7280	2.1100	289.835
.9535	2.7655	290.036
1.0275	2.9800	290.024
.9635	2.7980	290.399
.9255	2.6865	290.275
.7635	2.2175	290.438
		Mean, 290.306±.0436

Hence, Sb = 120.61.

[1] Proc. Amsterdam Acad., Section of Sciences, 5 (2), 543. 1903. See also Cohen, Collins and Strengers, Zeitsch. phys. Chem., 50, 291.
[2] Ber Deutsch. chem. Ges., 16, 1942. 1883.

Still another method of determination was adopted by Friend and Smith.[1] Potassium tartrylantimonite, $KSbC_4H_4O_7$, was heated in a stream of dry, gaseous hydrochloric acid, and so converted into potassium chloride. The results obtained, with vacuum weights, are subjoined:

$KSbC_4H_4O_7$.	*KCl.*	*Per cent KCl.*
1.19481	0.27539	23.049
1.57004	.36186	23.048
2.00912	.46307	23.048
2.04253	.47073	23.046
2.16646	.49935	23.049
2.25558	.51982	23.046
2.61255	.60215	23.048
.95272	.68064	23.051
		Mean, 23.048±.0006

Hence, Sb = 120.351.

We have now before us the following ratios, good and bad, from which to calculate the atomic weight of antimony. The single analyses by Weber and Unger, being unimportant, are not included:

(1) Percentage of S in Sb_2S_3, 28.5385±.0023.
(2) Percentage of Sb in Sb_2O_4, 79.283±.009.
(3) O needed to oxidize 100 parts $SbCl_3$, 7.0294±.0024.
(4) O needed to oxidize 100 parts Sb_2O_3, 10.953±.0075.
(5) O needed to oxidize 100 parts Sb, 13.079±.0096.
(6) $K_2Cr_2O_7$: tartar emetic :: 100 : 337.30±.29.
(7) 3Ag : $SbCl_3$ :: 100 : 70.512±.021.
(8) 3AgCl : $SbCl_3$ :: 100 : 53.2311±.008.
(9) 3Ag : $SbBr_3$ :: 100 : 111.114±.0014.
(10) 3AgBr : $SbBr_3$ :: 100 : 63.830±.008.
(11) 3AgI : SbI_3 :: 100 : 71.060±.023.
(12) 3Cu : 2Sb :: 100 : 128.259±.0077.
(13) 3Ag : Sb :: 100 : 37.452±.0119.
(14) 2Sb : $3BaSO_4$ :: 100 : 290.306±.0436.
(15) $KSbC_4H_4O_7$: KCl :: 100 : 23.048±.0006.

To reduce these ratios we have—

Ag=107.880 ±.00016	C = 12.0025±.00019
Cl= 35.4605±.00011	K = 39.0975±.00011
Br= 79.9228±.00015	Ba=137.358 ±.0023
I=126.926 ±.00023	Cr= 52.0193±.0013
S= 32.0650±.00012	Cu= 63.555 ±.0005
H=1.0078±.00001	

Hence,

From ratio—	
6	Sb=118.671±.2844
11	119.781±.1621
9	119.841±.0047
10	119.856±.0451
15	120.351±.0085
1	120.437±.0105
14	120.609±.0182
13	121.210±.0386
3	121.244±.0777
7	121.824±.0680
4	122.078±.0100
12	122.272±.0074
5	122.333±.0898
2	122.462±.0550
8	122.524±.0345
General mean	Sb=120.687±.0031

[1] Journ. Amer. Chem. Soc., 23, 502. 1901.

This mean has obviously very little significance except in so far as it shows the relatively low weight attaching to the higher values. The latter, say all over 121, are almost certainly in error, and ought to be rejected. Taking only the seven lowest values, they give a general mean of Sb = 120.062 ± .0037. Even this figure, however, is not quite satisfactory, for the values derived from ratios 1 and 15, which seem to be good, are not adequately accounted for. It is highly desirable that more work should be done upon the atomic weight of antimony by modern methods, and for the purpose, in part at least, of explaining some of the evident discrepancies which appear in the foregoing table.

BISMUTH.

Early in the last century an attempt was made by Lagerhjelm [1] to determine the atomic weight of bismuth, but the values he obtained were from four to seven units too high. They therefore need no further consideration here.

In 1851 the subject was taken up by Schneider,[2] who studied the oxidation of the metal with nitric acid. The work was executed with a variety of experimental refinements by means of which every error due to possible loss of material was carefully avoided. For full details the original paper must be consulted; there is only room in these pages for the actual results, as follows. The figures represent the percentages of Bi in Bi_2O_3:

89. 652	89. 656
89. 682	89. 666
89. 644	89. 655
89. 634	89. 653

Mean, 89. 6552 ± . 0034

Hence, Bi = 208.05.

Next in order are the determinations made by Dumas.[3] Bismuth trichloride was prepared by the action of dry chlorine upon bismuth, and repeatedly rectified by distillation over bismuth powder. The product was weighed in a closed tube, dissolved in water, and precipitated with sodium carbonate. In the filtrate, after strongly acidulating with nitric acid, the chlorine was precipitated by a known amount of silver. The figures in the third column show the quantities of $BiCl_3$ proportional to 100 parts of silver:

$BiCl_3$.	*Ag.*	*Ratio.*
3. 506	3. 545	98. 900
1. 149	1. 168	98. 373
1. 5965	1. 629	98. 005
2. 1767	2. 225	97. 829
3. 081	3. 144	97. 996
2. 4158	2. 470	97. 806
1. 7107	1. 752	97. 643
3. 523	3. 6055	97. 712
5. 241	5. 361	97. 762
		Mean, 98. 003 ± . 090

Hence, with Ag = 108 and Cl = 35.5, Bi = 211.03.

The first three of the foregoing experiments were made with slightly discolored material. The remaining six percentages give a mean of 97.791, whence, on the same basis as before, Bi = 110.79. Evidently these results are now of no real value, for it is probable that the chloride of bismuth, like the corresponding antimony compound, contained traces of oxychloride. This assumption fully accounts for the discordance between Dumas' determination and the determinations of Schneider and still more recent investigators.

In 1883 Marignac [4] took up the subject, attacking the problem by two methods. His point of departure was commercial subnitrate of bismuth, which was purified by re-solution and reprecipitation, and from which he prepared the oxide. First, bismuth trioxide was reduced

[1] Annals of Philosophy, 4, 358. 1814.
[2] Poggend. Annalen, 82, 303. 1851.
[3] Ann. Chim. Phys. (3), 55, 176. 1859.
[4] Arch. Sci. Phys. Nat. (3), 10, 10. Oeuvres Complètes, 2, 71".

by heating in hydrogen, beginning with a moderate temperature and closing the operation at redness. The results were as follows, with the percentage of Bi in Bi_2O_3 added:

Bi_2O_3.	O.	*Per cent.*
2. 6460	0. 2730	89. 683
6. 7057	. 6910	89. 696
3. 6649	. 3782	89. 681
5. 8024	. 5981	89. 692
5. 1205	. 5295	89. 658
5. 5640	. 5742	89. 680
		Mean, 89. 682 ± . 0036

Hence, Bi = 208.60.

Marignac's second method of determination was by conversion of the oxide into the sulphate. The oxide was dissolved in nitric acid, and then sulphuric acid was added in slight excess from a graduated tube. The mass was evaporated to dryness with great care, and finally heated over a direct flame until fumes of SO_3 no longer appeared. The third column gives the sulphate formed from 100 parts of oxide:

Bi_2O_3	$Bi_2(SO_4)_3$.	*Ratio.*
2. 6503	4. 0218	151. 749
2. 8025	4. 2535	151. 775
2. 710	4. 112	151. 734
2. 813	4. 267	151. 688
2. 8750	4. 3625	151. 739
2. 7942	4. 2383	151. 682
		Mean, 151. 728 ± . 0099

Hence, Bi = 208.17.

This result needs to be studied in the light of Bailey's observation,[1] that bismuth sulphate has a very narrow range of stability. It loses the last traces of free sulphuric acid at 405°, and begins to decompose at 418°, so that the foregoing ratio is evidently uncertain. The concordance of the data, however, is favorable to it.

Two analyses of bismuth sulphate, rather vaguely stated, are given by Bailey. The weights found, and the ratio derived from them are as follows:

$Bi_2(SO_4)_3$.	Bi_2O_3.	*Ratio.*
2. 2155	1. 4615	151. 591
1. 5635	1. 0267	152. 284
		Mean, 151. 937 ± . 231

Hence, Bi = 207.24. Combined with Marignac's series, the general mean becomes 151.729 ± .0099. Bailey's figures practically disappear.

The next determination of this atomic weight was by Löwe,[2] who oxidized the metal with nitric acid, and reduced the nitrate to oxide by ignition. Special care was taken to prepare bismuth free from arsenic, and the oxide was fused before weighing. In the paper just quoted Bailey calls attention to the volatility of bismuth oxide, which doubtless accounts for the low results found in this investigation. The data are as follows:

Bi taken.	Bi_2O_3 *found.*	*Per cent Bi.*
11. 309	12. 616	89. 640
12. 2776	13. 694	89. 656
		Mean, 89. 648 ± . 0040

Hence, Bi = 207.84.

In Classen's [3] work upon the atomic weight of bismuth, the metal itself was first carefully investigated. Commercial samples, even those which purported to be pure, were found to be contaminated with lead and other impurities, and these were not entirely removable by many

[1] Journ. Chem. Soc., 51, 676. 1887. Bailey deduces from his analyses Bi=208.33 and 208.43. There may be some error in his printed figures, for his deductions do not agree with the data as given.

[2] Zeit. anal. Chem., 22, 498.

[3] Ber. Deutsch. chem. Ges., 23, 938. 1890.

successive precipitations as subnitrate. Finally, pure bismuth was obtained by an electrolytic process, and this was converted into oxide by means of nitric acid and subsequent ignition to incipient fusion. Results as follows, with the percentage of Bi in Bi_2O_3 added:

Bi taken.	*Bi_2O_3 found.*	*Per cent Bi.*
25.0667	27.9442	89.703
21.0691	23.4875	89.7035
27.2596	30.3922	89.693
36.5195	40.7131	89.700
27.9214	31.1295	89.6944
32.1188	35.8103	89.692
30.1000	33.5587	89.694
26.4825	59.5257	89.693
19.8008	22.0758	89.695
		Mean, 89.696±.0009

Hence, Bi = 208.92, or, reduced to a vacuum, 208.90.

Classen's paper was followed by a long controversy between Schneider and Classen,[1] in which the former upheld the essential accuracy of the work done by Marignac and himself. Schneider had started out with commercial bismuth, and Classen found that the commercial bismuth which he met with was impure. Schneider, by various analyses, showed that other samples of bismuth were so nearly pure that the common modes of purification were adequate; but Classen replied that the original sample used by Schneider in his atomic weight investigation had not been reexamined. Accordingly, Schneider published a new series of determinations [2] made by the old method, but with metal which had been scrupulously purified. Results as follows:

Bi.	*Bi_2O_3.*	*Per cent Bi.*
5.0092	5.5868	89.661
3.6770	4.1016	89.648
7.2493	8.0854	89.659
9.2479	10.3142	89.662
6.0945	6.7979	89.653
12.1588	13.5610	89.660
		Mean, 89.657±.0015

Hence, with O = 16, Bi = 208.05, a confirmation of the earlier determinations.

According to Adie [3] the differences between the low and high values for bismuth are due to the presence of silicon in the metal. A preliminary determination of the atomic weight, made with pure bismuth, gave Bi = 208.8, approximately. Adie's explanation of the discrepancies remains to be substantiated by others.

Birckenbach,[4] working under the direction of Gutbier, effected the synthesis of bismuth oxide, and also studied its reduction. Bismuth from three distinct sources was employed in the investigation. First, the metal was converted into nitrate, and then calcined to oxide, which latter was proved to be free from occluded gases. The data obtained were as follows:

Preliminary Series.

Bi.	*Bi_2O_3.*	*Per cent Bi.*
10.2899	11.4782	89.647
8.1023	9.0372	89.655
		Mean, 89.651±.0027

Hence, BI = 207.905.

Final Series.

Bi.	*Bi_2O_3.*	*Per cent Bi.*
9.63289	10.74328	89.664
10.41101	11.61288	89.651
10.97914	12.24528	89.661

[1] Journ. prakt. Chem., 42, 563; 43, 133; 44, 23, and 411.

[2] Journ. prakt. Chem., 50, 461. 1894.

[3] Proc. Cambridge Phil. Soc., 12, 240. 1903.

[4] Inaug. Diss., Erlangen, 1905. The oxidation series also appears under the authorship of Gutbier and Birckenbach, in Journ. prakt. Chem. (2), 47, 457. 1908.

Bi.	Bi_2O_3.	*Per cent Bi.*
10.11990	11.28800	89.653
18.96770	21.15541	89.659
11.99601	13.38001	89.654
27.23022	30.37392	89.651
24.98170	27.86431	89.655
10.11284	11.27998	89.653
28.35991	31.63053	89.660
		Mean, 89.656±.0010

Hence, Bi = 208.02.

The reduction of bismuth oxide to bismuth gave Birckenbach the following results:

Preliminary Series.

Bi_2O_3.	*Bi.*	*Per cent Bi.*
2.43105	2.17994	89.671
2.9547	2.6488	89.647
1.65199	1.4810	89.671
2.4103	2.1609	89.653
		Mean, 89.660±.0041

Hence, Bi = 208.11.

Final Series.

Bi_2O_3.	*Bi.*	*Per cent Bi.*
1.45827	1.30751	89.662
2.12432	1.90461	89.657
3.0021	2.6918	89.664
2.1012	1.8840	89.663
3.0182	2.70620	89.663
1.9091	1.71171	89.661
		Mean, 89.662±.0007

Hence, Bi = 208.153.

The data for the percentage of Bi in Bi_2O_3 now combine as follows:

Schneider, 1851	89.655±.0034
Marignac	89.682±.0036
Löwe	89.648±.0040
Classen	89.696±.0009
Schneider, 1894	89.657±.0015
Birckenbach, preliminary oxidations	89.651±.0027
Birckenbach, final oxidations	89.656±.0010
Birckenbach, preliminary reductions	89.660±.0041
Birckenbach, final reductions	89.662±.0007
General mean	89.6683±.00044

If we omit the high value found by Classen, the general mean becomes 89.6594±.00052.

Mehler,[1] also under Gutbier's direction, studied the composition of bismuth tribromide, which was prepared by direct union of the metal with bromine, and afterwards sublimed. The bromine was precipitated with silver solution, and the silver bromide was weighed. The weights are given as reduced to a vacuum. In the third column I give the ratio $3AgBr : BiBr_3 :: 100 : x$:

$BiBr_3$.	*AgBr.*	*Ratio.*
3.77071	4.74323	79.497
4.37676	5.50932	79.443
3.64088	4.58160	79.467
4.57894	5.76183	79.470
4.53204	5.70410	79.452
2.85054	3.58682	79.473
4.58310	5.76618	79.482
6.47910	8.15465	79.453
		Mean, 79.467±.0042

Hence, Bi = 207.96.

[1] Inaug. Diss., Erlangen, 1905. Sitzungsb. phys. med. Soz. Erlangen, 37, 343.

Another research, carried out under Gutbier by Janssen,[1] involved the synthesis of bismuth sulphate. Bismuth was first dissolved in nitric acid, and then, with sulphuric acid, converted into sulphate. The latter compound was freed from moisture and excess of acid by heating to 380°, at which temperature its weight was constant. The results obtained were as follows:

Bi.	$Bi_2(SO_4)_3$.	*Per cent Bi.*
2.4045	4.0706	59.070
2.41900	4.09445	59.081
2.20280	3.72745	59.096
2.57206	4.35444	59.066
5.79241	3.79987	59.106
3.65233	6.18143	59.086
		Mean, 59.084±.0042

Hence, Bi=208.081.

The recent determinations of the atomic weight of bismuth by Oechsner de Coninck and Gérard,[2] are based upon the reduction of the trichloride to metal by heating in a stream of hydrogen. Their data are as follows:

$BiCl_3$.	*Bi.*	*Per cent Bi.*
0.6100	0.4038	66.197
.5490	.3634	66.193
.4880	.3230	66.188
.4930	.3263	66.187
		Mean, 66.191±.0017

Hence, Bi=208.273.

Rejecting the work of Dumas, the following ratios are now available for discussion:

(1) $Bi_2O_3 : 2Bi :: 100 : 89.6683 \pm .00044$.
(2) $Bi_2(SO_4)_3 : 2Bi :: 100 : 59{,}084 \pm .0042$.
(3) $Bi_2O_3 : Bi_2(SO_4)_3 :: 100 : 151.729 \pm .0099$.
(4) $BiCl_3 : Bi :: 100 : 66.191 \pm .0017$.
(5) $3AgBr : BiBr_3 :: 100 : 79.467 \pm .0042$.

To reduce these ratios we have—

Ag=107.880±.00016 Br=79.9228±.00015
Cl=35.4605±.00011 S=32.065 ±.00012

Hence,

From ratio—

5	Bi=207.956±.0238
2	208.081±.0260
3	208.117±.0444
4	208.273±.0118
1	208.295±.0095
General mean	Bi=206.240±.0065

This value is probably too high, mainly because of Classen's determinations. Rejecting them the general mean becomes

$$Bi = 208.063 \pm .0071$$

which value is to be accepted. It is also sustained by Brauner's[3] statement that Kužma, by syntheses of bismuth sulphate from bismuth oxide, has obtained the value Bi=208.0±.1. The details of Kužma's work are yet to be published.

COLUMBIUM.[4]

The atomic weight of this metal has been determined by several investigators. Rose[5] analyzed a compound which he supposed to be chloride, but which, according to Rammelsberg,[6] must have been nearly pure oxychloride. If it was chloride, then the widely varying results give approximately Cb=122; if it was oxychloride, the value becomes nearly 94. If it was chloride, it was doubtless contaminated with tantalum compounds.

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[1] Inaug. Diss., Erlangen, 1906.
[2] Compt. Rend., 162, 252. 1916.
[3] In Abegg's "Handbuch," 3 (3), 634.
[4] This name has 40 years' priority over "niobium," and therefore deserves preference.
[5] Poggend. Annal., 101, 439. 1858.
[6] Poggend. Annal., 136, 353. 1869.

Hermann's [1] results seem to have no present value, and Bloomstrand's [2] are very discordant. He analyzed columbium pentachloride and sodium columbate, but his compounds could not have been pure. They evidently contained some tantalum, for the atomic weights deduced from his analyses are several units too high.

Marignac [3] made about 20 analyses of potassium fluoxycolumbate, $CbOF_3.2KF.H_2O$. One hundred parts of this salt give the following percentages:

Cb_2O_5	Extremes 44.15 to 44.60	Mean, 44.36
K_2SO_4	" 57.60 to 58.05	
H_2O	" 5.75 to 5.98	
F	" 30.62 to 32.22	

From the mean percentage of Cb_2O_5, Cb = 93.418.

From the mean between the extremes given for K_2SO_4, Cb = 93.95.

The recent determinations by Balke and Smith[4] are much more satisfactory than those already cited. Their material was certainly purer, and the results obtained were highly concordant. Columbium pentachloride was decomposed by water, with the aid of a little nitric acid, and the oxide so produced was finally ignited and weighed. Their data, with vacuum weights, are as follows:

$CbCl_5$.	*Cb_2O_5.*	*Pr. cent Cb_2O_5.*
9.56379	4.71539	49.305
5.42742	2.65730	49.292
5.15992	2.54364	49.296
9.64854	4.75641	49.297
7.24572	3.57222	49.301
8.00559	3.94746	49.309
9.60763	4.73852	49.324
9.19732	4.53638	49.323
4.27456	2.10734	49.300
		Mean, 49.305 ± .0026

Hence, with Cl = 35.4605 ± .00011, Cb = 93.538 ± .0139.

The determinations of the atomic weight of columbium by Smith and Van Haagen[5] were made by heating sodium columbate in the vapor of sulphur monochloride. The columbium was volatilized as chloride or oxychloride, and sodium chloride remained behind. The data, with vacuum weights, are as follows:

$NaCbO_3$.	*NaCl.*	*Pr. cent NaCl.*
0.36419	0.12975	35.627
.69113	.24617	35.618
1.04904	.37368	35.621
1.64337	.58516	35.607
1.33367	.47487	35.606
.88051	.31366	35.623
1.29947	.46289	35.622
		Mean, 35.618 ± .0021

Hence, with Na = 23.0029 ± .00012, Cb = 93.137 ± .0097.

Combining this value with that derived from the chloride, the general mean for columbium becomes

$$Cb = 93.277 \pm .0078$$

This final mean is not altogether satisfactory. As Smith and Van Haagen point out, columbium pentachloride is likely to contain some oxychloride, which tends to increase the

[1] Journ. prakt. Chem., 68, 73. 1856.
[2] Acta Univ. Lund, 1864.
[3] Arch. Sci. Phys. Nat. (2), 23. 1865. Oeuvres Complètes, 2, 259.
[4] Journ. Amer. Chem. Soc., 30, 1644. 1908.
[5] Journ. Amer. Chem. Soc., 37, 1783. 1915.

atomic weight derived from it. On the other hand it is not absolutely certain that the sodium columbate did not contain traces of water, not entirely removable by ordinary drying. That error, if it existed, would lead to an atomic weight slightly too low. In the final combination of the two values these possible errors should tend to compensation. More evidence is needed before the atomic weight of columbium can be accurately fixed.

TANTALUM.

The determinations of the atomic weight of tantalum by Berzelius,[1] Rose,[2] Hermann,[3] and Blomstrand [4] may be fairly left out of account as valueless. These chemists could not have worked with pure preparations, and their results are sufficiently summed up in Becker's "Digest," and also in the previous editions of this work.

In 1866 Marignac's determinations appeared.[5] He made four analyses of a pure potassium fluotantalate, and four more experiments upon the ammonium salt. The potassium compound, K_2TaF_7, was treated with sulphuric acid, and the mixture was then evaporated to dryness. The potassium sulphate was next dissolved out by water, while the residue was ignited and weighed as Ta_2O_5. One hundred parts of the salt gave the following quantities of Ta_2O_5 and K_2SO_4 :

Ta_2O_5.	*K_2SO_4.*
56. 50	44. 37
56. 75	44. 35
56. 55	44. 22
56. 56	44. 24
Mean, 56. 59±. 037	Mean, 44. 295±. 026

From these figures, 100 parts of K_2SO_4 correspond to the subjoined quantities of Ta_2O_5:

127. 338 128. 178
127. 960 127. 848
Mean, 127. 831±. 120

The ammonium salt $(NH_4)_2TaF_7$, ignited with sulphuric acid, gave these percentages of Ta_2O_5. The figures are corrected for a trace of K_2SO_4 which was always present:

63. 08 63. 27
63. 24 63. 42
Mean 63. 25±. 047

Hence we have four values for Ta:

From potassium salt, per cent Ta_2O_5	Ta=183. 55
From potassium salt, per cent K_2SO_4	" =182. 93
From potassium salt, K_2SO_4 : Ta_2O_5	" =182. 76
From ammonium salt, per cent Ta_2O_5	" =182. 66
Average	Ta=182. 975

The determinations by Hinrichsen and Sahlbom [6] were much simpler. Metallic tantalum was converted into pentoxide by heating in oxygen, and the composition of the oxide was so ascertained. The weights and percentages of tantalum are as follows:

Ta.	*Ta_2O_5.*	*Pr. cent Ta.*
0. 37200	0. 45437	81. 872
. 41278	. 50364	81. 959
. 33558	. 40975	81. 899
. 35883	. 43807	81. 912
. 47554	. 58087	81. 868
		Mean, 81. 902±. 0111

Hence, Ta = 181.019 ± .0857.

[1] Poggend. Annalen, 4, 14. 1825.
[2] Poggend. Annalen, 99, 80. 1856.
[3] Journ. prakt. Chem., 70, 193. 1857.
[4] Acta Univ. Lund, 1864.
[5] Arch. Sci. Phys. Nat. (2), 26, 89. 1866. Oeuvres Completes, 2, 314.
[6] Bev. Deutsch. Chem. Ges., 39, 2600, 1906.

This mean value has very little significance, because the individual determinations give values for the atomic weight of tantalum ranging from 180.60 to 181.72; a difference of 1.12 units.

The determinations by Van Haagen [1] are confessedly approximate, because the material studied may not have been absolutely pure. Tantalum pentabromide was hydrolyzed to oxide, giving the ratio $TaCl_5 : Ta_2O_5 :: 100 : x$. The bromide, however, may have contained traces either of an oxybromide or, as Van Haagen supposes, of an addition product of $TaBr_5$ and HBr. Two series of determinations are given, but without correction to a vacuum. The data are as follows; both series taken as one.

$TaBr_5$.	*Ta_2O_5.*	*Per cent Ta_2O_5.*
1. 11049	0. 42528	38. 297
. 63125	. 24187	38. 316
1. 64424	. 62951	38. 286
1. 54531	. 59209	38. 315
. 25094	. 09616	38. 320
2. 13436	. 81737	38. 296
1. 08818	. 41678	38. 301
2. 21255	. 84779	38. 317
		Mean, 38. 306±. 0044

Hence Ta = 183.284 ± . 0871.

Two years later, also in the laboratory of the University of Pennsylvania, Chapin and Smith [2] made a series of analyses of tantalum pentabromide, by the method of hydrolysis. Their data, with vacuum weights, are as follows

$TaBr_5$.	*Ta_2O_5.*	*Per cent Ta_2O_5.*
0. 86837	0. 33117	38. 137
1. 50903	. 57570	38. 150
1. 56554	. 59718	38. 145
1. 23239	. 47030	38. 162
1. 31815	. 50295	38. 156
1. 31702	. 50244	38. 150
1. 20090	. 45830	38. 163
1. 04050	. 39688	38. 143
		Mean, 38. 151±. 0022

Hence Ta = 181.822 ± .0414.

Similar hydrolyses of tantalum pentachloride were effected by Balke.[3] His data, with vacuum weights, are as follows:

$TaCl_5$.	*Ta_2O_5.*	*Per cent Ta_2O_5.*
12. 99680	8. 02326	61. 733
9. 24957	5. 71104	61. 744
10. 17456	6. 28133	61. 736
17. 99542	11. 11014	61. 739
11. 70588	7. 22693	61. 739
6. 24767	3. 85658	61. 728
7. 26375	4. 48398	61. 731
15. 88270	9. 80465	61. 732
		Mean, 61. 735±. 0012

Hence Ta = 181.524 ± .0225.

Sears and Balke [4] first studied the hydrolysis of tantalum pentachloride, and found two important sources of error in the process. Some nitric acid was retained by the tantalic oxide, and some of the latter was lost during ignition. They therefore abandoned that method as unsuited to the accurate determination of the atomic weight of tantalum, and resorted to a study, which they term preliminary, of the ratio between the chloride and silver. Three sets of determinations are given, with vacuum weights, as follows:

[1] Thesis, University of Pennsylvania, 1909.
[2] Journ. Amer. Chem. Soc., 33, 1497. 1911.
[3] Journ. Amer. Chem. Soc., 32, 1127. 1910.
[4] Journ. Amer. Chem. Soc., 37, 833. 1915.

Series 1.

$TaCl_5$.	Ag.	Ratio.
11. 66795	17. 51344	66. 622
7. 61398	11. 42585	66. 638
4. 09519	6. 15647	66. 518
8. 09039	12. 16628	66. 498
		Mean, 66. 569±. 0252

Hence Ta = 181.771.

Series 2.

$TaCl_5$.	Ag.	Ratio.
3. 53605	5. 31834	66. 488
2. 99083	4. 49851	66. 485
6. 21118	9. 34345	66. 476
		Mean, 66. 483±. 0031

Hence Ta = 181.307.

Series 3.

$TaCl_5$.	Ag.	Ratio.
4. 03892	6. 07417	66. 493
3. 32164	5. 00133	66. 417
2. 68304	4. 04002	66. 412
3. 01453	4. 53953	66. 406
3. 95846	5. 95931	66. 425
		Mean, 66. 431±. 0107

Hence Ta = 181.027. The three series combined give a general mean value for the ratio of 5Ag : $TaCl_5$: : 100 : 66.479 ± .0029.

Hence—

Ta = 181.290 ± .0157.

In this combination series 2 is evidently much overvalued. Series 3 is underrated because the first determination in it varies much from the others. These considerations, however, carry little weight, for the method of determination, as Sears [1] has shown, is subject to serious errors. Indeed, according to Sears, tantalum pentachloride is not a trustworthy compound to use in atomic weight determinations.

In the present state of our knowledge it is not necessary to combine the various determinations of the atomic weight of tantalum into a general mean. The following table, however, may be useful as a comparison of the results so far obtained. In it the determinations by Marignac are arbitrarily assigned equal weight with those by Van Haagen.

Marignac	Ta=182. 975±. 0871
Hinrichsen and Sahlbom	181. 019±. 0857
Van Haagen	183. 284±. 0871
Chapin and Smith	181. 822±. 0414
Balke	181. 524±. 0225
Sears and Balke	181. 290±. 0157

From these figures no final conclusion can be drawn. So far as present evidence goes, it seems probable that the atomic weight of tantalum is somewhere near 181, with an uncertainty of at least half a unit.

CHROMIUM.

Concerning the atomic weight of chromium there has been much discussion, and many experimenters have sought to establish the true value. The earliest work upon it having any importance was that of Berzelius,[2] in 1818 and 1826, which led to results much in excess of the correct figure. His method consisted in precipitating a known weight of lead nitrate with an alkaline chromate and weighing the lead chromate thus produced. The error in his determina-

[1] Journ. Amer. Chem. Soc., 39, 1852. 1917.

[2] Schweigg. Journ., 22, 53, and Poggend. Annal., 8, 22.

tion arose from the fact that lead chromate, except when thrown down from very dilute solutions, carries with it minute quantities of alkaline salts, and so has its apparent weight notably increased. When dilute solutions are used, a trace of the precipitate remains dissolved, and the weight obtained is too low. In neither case is the method trustworthy.

In 1844 Berzelius' results were first seriously called in question. The figure for chromium deduced from his experiments was somewhat over 56; but Peligot[1] now showed, by his analyses of chromous acetate and of the chlorides of chromium, that the true number was near 52.5. Unfortunately, Peligot's work, although good, was published with insufficient details to be useful here. For chromous acetate he gives the percentages of carbon and hydrogen, but not the actual weights of salt, carbon dioxide, and water from which they were calculated. His figures vary considerably, moreover—enough to show that their mean would carry but little weight when combined with the more explicit data furnished by other chemists.

Jacquelain's[2] work we may omit entirely. He gives an atomic weight for chromium which is notoriously too low (50.1), and prints none of the numerical details upon which his result rests. The determinations by Moberg,[3] Lefort,[4] and Wildenstein,[5] which give values for chromium in excess of Cr = 53, may also be rejected, and given no further consideration. The first researches to command our attention are those by Berlin.[6] His starting point was normal silver chromate; but in one experiment the dichromate $Ag_2Cr_2O_7$ was used. These salts, which are easily obtained in a pure condition, were reduced in a large flask by means of hydrochloric acid and alcohol. The chloride of silver thus formed was washed by decantation, dried, fused, and weighed without transfer. The united washings were supersaturated with ammonia, evaporated to dryness, and the residue treated with hot water. The resulting chromic oxide was then collected upon a filter, dried, ignited, and weighed. The results were as follows:

4.6680 grm. Ag_2CrO_4	gave	4.027 grm.	AgCl	and 1.0754 grm.	Cr_2O_3.
3.4568	"	2.983	"	.7960	"
2.5060	"	2.1605	"	.5770	"
2.1530	"	1.8555	"	.4945	"
4.3335 grm. Ag_2CrO_7	gave	2.8692	"	1.5300	"

From these weighings three values are calculable for the atomic weight of chromium. The three ratios upon which these values depend we will consider separately, taking first that between the chromic oxide and the original silver salt. In the four analyses of the normal chromate the percentages of Cr_2O_3 deducible from Berlin's weighings are as follows:

23.037	23.025
23.027	22.968

Mean, 23.014 ± .011

Hence, Cr = 52.46.

And from the single experiment with $Ag_2Cr_2O_7$ the percentage of Cr_2O_3 was 35.306. Hence, Cr = 52.34.

For the ratio between Ag_2CrO_4 and AgCl, putting the latter at 100, we have for the former:

115.917	115.992
115.883	116.033

Mean, 115.956 ± .023

Hence, Cr = 52.66.

In the single experiment with dichromate 100 AgCl is formed from 151.035 $Ag_2Cr_2O_7$. Hence, Cr = 52.61.

Finally, for the ratio between AgCl and Cr_2O_3, the five experiments of Berlin give, for 100 parts of the former, the following quantities of the latter:

26.705	26.650
26.685	26.662
26.707	

Mean, 26.682 ± .0076

Hence, Cr = 52.50.

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[1] Compt. Rend., 19, 609, and 734; 20, 1187; 21, 74.
[2] Compt. Rend., 24, 679. 1847.
[3] Journ. prakt. Chem., 43, 114.
[4] Journ. prakt. Chem., 50, 261. 1850.
[5] Journ. prakt. Chem., 59, 27.
[6] Journ. prakt. Chem., 37, 509, and 38, 149. 1846.

Next in order are two papers by Kessler, who employed a peculiar volumetric method entirely his own. In brief, he compared the oxidizing power of potassium dichromate with that of the chlorate, and from his observations deduced the ratio between the molecular weight of the two salts.

In his earlier paper[1] the mode of procedure was about as follows: The two salts, weighed out in quantities having approximate chemical equivalency, were placed in two small flasks, and to each was added 100 cc. of a ferrous chloride solution and 30 cc. hydrochloric acid. The ferrous chloride was added in trifling excess, and, when action ceased, the amount unoxidized was determined by titration with a standard solution of dichromate. As in each case the quantity of ferrous chloride was the same, it became easy to deduce from the data thus obtained the ratio in question. I have reduced all of his somewhat complicated figures to a simple common standard, and give below the amount of chromate equivalent to 100 parts of chlorate.

120.118	120.096
120.371	120.241
120.138	120.181

Mean, 120.191±.028

Hence, Cr=52.21.

In his later paper[2] Kessler substituted arsenic trioxide for the iron solution. In one series of experiments the quantity of dichromate needed to oxidize 100 parts of the arsenic trioxide was determined, and in another the latter substance was similarly compared with the chlorate. The subjoined columns give the quantity of each salt proportional to 100 parts of As_2O_3:

$K_2Cr_2O_7$.	$KClO_3$.
98.95	41.156
98.94	41.116
99.17	41.200
98.98	41.255
99.08	41.201
99.15	41.086
	41.199
	41.224
	41.161
	41.193
	41.149
	41.126
Mean, 99.045±.028	Mean, 41.172±.009

Hence, Cr=52.32.

Reducing the later series to the standard of the earlier, the two combine as follows:

(1) $2KClO_3 : K_2Cr_2O_7 :: 100 : 120.191 \pm .028$

(2) $2KClO_3 : K_2Cr_2O_7 :: 100 : 120.282 \pm .043$

General mean, $120.216 \pm .0235$

Siewert's determinations, which do not seem to have attracted general attention, were published in 1861.[3] He, reviewing Berlin's work, found that upon reducing silver chromate with hydrochloric acid and alcohol, the chromic chloride solution always retained traces of silver chloride dissolved in it. These could be precipitated by dilution with water; but, in Berlin's process, they naturally came down with the chromium hydroxide, making the weight of the latter too high; hence too large a value for the atomic weight of chromium. In order to find a more correct value Siewert resorted to the analysis of sublimed, violet, chromic chloride. This salt he fused with sodium carbonate and a little nitre, treated the fused mass with water, and precipitated from the resulting solution the chlorine by silver nitrate in presence of nitric acid. The weight of the silver chloride thus obtained, estimated after the usual manner, gave means for calculating the atomic weight of chromium. His figures, reduced to a common standard, give, as proportional to 100 parts of chloride of silver, the quantities of chromic chloride stated in the third of the subjoined columns:

[1] Poggend. Annalen, 95, 208. 1855. [2] Poggend. Annalen, 113, 137. 1861. [3] Zeit. gesammt. Wissenschaften, 17, 530.

$CrCl_3$.	$AgCl$.	Ratio.
0.2367	0.6396	37.007
.2946	.7994	36.853
.2593	.7039	36.838
.4935	1.3395	36.842
.5850	1.5884	36.830
.6511	1.76681	36.852
.5503	1.49391	36.836
		Mean, 36.865±.0158

The first of these figures varies so widely from the others that we are justified in rejecting it, in which case the mean becomes 36.842±.0031. Hence, Cr=52.048.

Siewert also made two analyses of silver dichromate by the following process. The salt, dried at 120°, was dissolved in nitric acid. The silver was then thrown down by hydrochloric acid, and, in the filtrate, chromium hydroxide was precipitated by ammonia. Reduced to a uniform standard, we find from his results, corresponding to 100 parts of AgCl, $Ag_2Cr_2O_7$ as in the last column:

$Ag_2Cr_2O_7$.	$AgCl$.	Cr_2O_3.	Ratio.
0.7866	0.52202	0.2764	150.684
1.089	.72249	.3840	150.729
			Mean, 150.706

Hence, Cr=52.14.

Berlin's single determination of this ratio gave 151.035. Taking all three values together as one series, they give a mean of 150.816±.074.

Siewert's percentages of Cr_2O_3 obtained from $Ag_2Cr_2O_7$ are as follows, calculated from the above weighings:

35.139
35.262

Mean, 35.2005±.0415

Hence, Cr=51.983.

Combining, as before, with Berlin's single result, giving the latter equal weight with one of these, we have a general mean of 35.236±.0335.

For the ratio between silver chloride and chromic oxide, Siewert's two analyses of the dichromate give as follows. For 100 parts of AgCl we have of Cr_2O_3:

52.948
53.150

Mean, 53.049±.068

Hence, Cr=52.041.

This figure, reduced to the standard of Berlin's work on the monochromate, becomes 26.525±.034. Berlin's mean was 26.682±.0076. The two means, combined, give a general mean of 26.676±.074.

By Baubigny[1] we have only three experiments upon the calcination of anhydrous chromic sulphate, as follows:

$Cr_2(SO_4)_3$.	Cr_2O_3.	Per cent.
1.989	0.7715	38.788
3.958	1.535	38.782
2.6052	1.0115	38.826
		Mean, 38.799±.0092

Hence, Cr=52.14.

In Rawson's work[2] ammonium dichromate was the substance studied. Weighed quantities of this salt were dissolved in water, and then reduced by hydrochloric acid and alcohol. After evaporation to dryness the mass was treated with water and ammonia, reevaporated,

[1] Compt. Rend., 98, 146. [2] Journ. Chem. Soc., 55, 213.

dried five hours at 140°, and finally ignited in a muffle. The residual chromic oxide was bright green, and was tested to verify its purity. The corrected weights are as follows:

$Am_2Cr_2O_7$.	Cr_2O_3.	Per cent Cr_2O_3.
1. 01275	0. 61134	60. 365
1. 08181	. 65266	60. 330
1. 29430	. 78090	60. 334
1. 13966	. 68799	60. 368
. 98778	. 59595	60. 332
1. 14319	. 68987	60. 346
		Mean, 60. 346±. 0046

Hence, Cr = 52.15.

Still later we come to the elaborate determinations of the atomic weight of chromium made by Meineke,[1] who studied the chromate and ammonio-chromate of silver, and also the dichromates of potassium and ammonium. For the latter salt he measured the same ratio that Rawson determined, but by a different method. He precipitated its solution with mercurous nitrate, and ignited the precipitate, with the subjoined results. Vacuum weights are given:

$Am_2Cr_2O_7$.	Cr_2O_3.	Per cent Cr_2O_3.
2. 0416	1. 2316	60. 325
2. 1618	1. 3040	60. 320
2. 0823	1. 2562	60. 328
2. 1913	1. 3221*	60. 335
2. 0970	1. 2656	60. 353
		Mean, 60. 332±. 0037
		Rawson found, 60.346±. 0046
		General mean, 60. 337±. 0029

From Meineke's figures Cr = 52.11.

The chromate of silver, Ag_2CrO_4, and the ammonio-chromate, $Ag_2CrO_4.4NH_3$, both prepared with all necessary precautions to insure purity, were first treated essentially as in Berlin's experiments, except that the traces of silver chloride held in solution by the chromic chloride were thrown out by sulphuretted hydrogen, estimated, and their amount added to the main portion. Thus the chief error in Berlin's work was avoided. I subjoin the data obtained, with vacuum standards, as usual. All of Meineke's results are so corrected:

Ag_2CrO_4.	$AgCl$.	Cr_2O_3.
2. 7826	2. 4047	0. 6384
3. 2627	2. 8199	. 7480
3. 6362	3. 1416	. 8338
4. 6781	4. 0414	1. 0726
3. 2325	2. 7930	. 7411
3. 9137	3. 3805	. 8976

Hence we have the following ratios, as in the case of Berlin's data:

Per cent Cr_2O_3.	100 $AgCl:Ag_2CrO_4$.	100 $AgCl:Cr_2O_3$.
22. 943	115. 715	26. 548
22. 926	115. 703	26. 526
22. 931	115. 744	26. 602
22. 928	115. 754	26. 601
22. 924	115. 736	26. 531
22. 935	115. 773	26. 552
Mean, 22. 931±. 0019	Mean, 115. 737±. 0072	Mean, 26. 560±. 0093
Berlin, 23. 014±. 0110		
General mean, 22. 934±. 0018		

From Meineke's figures Cr = 52.10, 52.04 and 52.14.

[1] Ann. Chem., 261, 339. 1891. * Calculated back from Meineke's value for Cr to replace an evident misprint in the original.

With the ammonio-chromate Meineke found as follows:

$Ag_2CrO_4.4NH_3$.	$AgCl$.	Cr_2O_3.
4.1518	2.9724	0.7904
4.2601	3.0592	.8125
5.9348	4.2654	1.1317

And the ratios become—

Per cent Cr_2O_3.	*100 AgCl:Salt.*	*100 AgCl:*Cr_2O_3.
19.037	139.679	26.591
19.072	139.255	26.559
19.059	139.138	26.532
Mean, 19.059±.0074	Mean, 139.357±.1109	Mean, 26.561±.0115
Cr=52.27	Cr=51.61	Cr=52.144

The first of these three analyses is rejected by Meineke as suspicious, but for the present I shall allow it to remain. The data in the third column may now be combined with the corresponding figures from the normal chromate, as found by Meineke and his predecessors:

Berlin	26.682±.0076
Siewert, from $Ag_2Cr_2O_7$	26.525±.0340
Meineke, from Ag_2CrO_4	26.560±.0093
Meineke, from $Ag_2CrO_4.4NH_3$	26.561±.0115
General mean	26.620±.0052

$$4\ AgCl : Cr_2O_3 :: 100 : 26.620 \pm .0052$$

Obviously, this mean is vitiated by the known error in Berlin's work, the ultimate effect of which is serious.

In all four of the salts studied by Meineke he determined volumetrically the oxygen in excess of the normal oxides by measuring the amount of iodine liberated in acid solutions. With the silver salts the process was essentially as follows: A weighed quantity of the chromate was dissolved in weak ammonia, and the solution was precipitated with potassium iodide. After the silver iodide had been filtered off, five or six grams of potassium iodide were added to the filtrate, which was then acidulated with phosphoric acid and a little sulphuric. The liberated iodine was then titrated with sodium thiosulphate solution, which had been standardized by means of pure iodine, prepared by Stas' method. From the iodine thus measured the excessive oxygen was computed, and from that datum the atomic weight of chromium was found. For present purposes, however, the data may be used more directly, as giving the ratios $3I : Ag_2CrO_4$ and $3I : Ag_2CrO_4.4NH_3$. Thus treated, the weights are as follows, reduced to a vacuum. Reckoning the salt as 100, the third column gives the percentage of iodine liberated:

Ag_2CrO_4.	*I Set Free.*	*Percentage.*
0.43838	0.50251	114.628
.90258	1.03432	114.595
.89858	1.02980	114.603
.89868	1.03072	114.693
		Mean, 114.630±.015

Hence, Cr=52.42.

The next series, obviously, gives the ratio $3I : Ag_2CrO_4.4NH_3$:

$Ag_2CrO_4.4NH_3$.	*I Set Free.*	*Percentages.*[1]
0.54356	0.51784	95.267
.54856	.52046	94.877
.54926	.52322	95.258
.54906	.52376	95.392
.54466	.51910	95.307
.54536	.51891	95.150
		Mean, 95.208±.0497

Hence, Cr=52.097.

[1] These figures are not wholly in accord with the percentages of oxygen computed by Meineke. I suspect that there is a misprint among his data as published, probably in the second experiment, but I cannot trace it with certainty.

In dealing with the two dichromates Meineke used the acid potassium iodate in place of potassium iodide, the chromate and the iodate reacting in the molecular ratio of 2 : 1. The thiosulphate was standardized by means of the acid iodate, so that we have direct ratios between the latter and the two chromates. The data are as follows, with the amount of iodate proportional to one hundred parts of the dichromate in the third column:

$K_2Cr_2O_7$.	KHI_2O_6.	*Percentage.*
0. 25090	0. 16609	66. 198
. 25095	. 16613	66. 200
. 25078	. 16601	66. 197
. 24979	. 16541	66. 220
. 24987	. 16540	66. 192
. 24966	. 16543	66. 262
. 25015	. 16559	66. 196
. 25012	. 16559	66. 204
. 24977	. 16546	66. 245
. 25034	. 16572	66. 198
. 25025	. 16567	66. 202
. 25015	. 16568	66. 234
		Mean, 66. 212±. 0044

Hence Cr = 52.14.

$Am_2Cr_2O_7$.	KHI_2O_6.	*Percentage.*
0. 21457	0. 16584	77. 290
. 21465	. 16588	77. 279
. 21464	. 16584	77. 264
. 21416	. 16543	77. 246
. 21447	. 16564	77. 232
. 21427	. 16559	77. 281
. 22196	. 17152	77. 272
. 22194	. 17151	77. 278
. 22180	. 17139	77. 272
		Mean, 77. 268±. 0041

Hence, Cr = 52.13.

Baxter, Mueller, and Hines[1] determined the atomic weight of chromium by the analysis of silver chromate. The weighed salt was dissolved in nitric acid and reduced either by sulphurous acid or hydrazine sulphate. The silver was then precipitated as chloride or bromide, by weak hydrochloric or hydrobromic acid, and the halide compound was weighed. All modern precautions were taken in this work, such as determining traces of moisture in the chromate, and also the traces of silver chloride or bromide remaining in solution. The chloride series, with vacuum weights, was as follows:

Ag_2CrO_4.	$AgCl$.	*Ratio.*
10. 30985	8. 90908	115. 723
8. 26920	7. 14492	115. 735
5. 56679	5. 67444	115. 726
		Mean, 115. 728±. 0024

Hence, Cr = 52.010.

This combines with previous series as follows:

Berlin	115. 956±. 023
Meineke	115. 737±. 0072
Baxter et al	115. 728±. 0024
General mean	115. 731±. 0023

For the bromide series, all corrections applied, the data are these:

Ag_2CrO_4.	$AgBr$.	*Ratio.*
2. 63788	2. 98621	88. 336
2. 82753	3. 20084	88. 337

[1] Journ. Amer. Chem. Soc., 31, 529. 1909.

Ag_2CrC_4.	$AgBr$.	Ratio.
2.33454	2.64268	88.340
1.77910	2.01402	88.336
2.33198	2.63994	88.335
3.10402	3.51390	88.336
2.92751	3.31427	88.330
4.21999	4.77762	88.328
5.24815	5.94104	88.337
6.24014	7.06484	88.327
7.92313	8.96982	88.331
		Mean, 88.334±.0009

Hence, Cr = 52.028. Similar determinations of the atomic weight of chromium were made by Baxter and Jesse,[1] who analyzed silver dichromate. In a single experiment 6.26657 grammes of $Ag_2Cr_2O_7$ gave 4.16076 of AgCl. Ratio, 150.611. Giving this the weight of a single determination in the following bromide series ±.0024, it combines with the earlier measurements by Berlin and Siewert to a general mean of 150.612±.0024. The older work vanishes. Hence Cr = 52.003.

The dichromate-bromide series of determinations gave the subjoined data:

$Ag_2Cr_2O_7$.	$AgBr$.	Ratio.
5.71554	4.97149	114.966
4.87301	4.23888	114.960
7.45476	6.48425	114.967
4.75269	4.13420	114.960
8.15615	7.09495	114.957
6.15412	5.35309	114.964
6.83662	5.94768	114.963
5.39883	4.69631	114.959
		Mean, 114.962±.0008

Hence, Cr = 52.022.

The following ratios are now available for computing the atomic weight of chromium:

(1) Percentage Cr_2O_3 from Ag_2CrO_4, 22.934±.0018.
(2) Percentage Cr_2O_3 from $Ag_2Cr_2O_7$, 35.236±.0335.
(3) $2AgCl : Ag_2CrO_4 :: 100 : 115.731 \pm .0023$.
(4) $2AgCl : Ag_2Cr_2O_7 :: 100 : 150.612 \pm .0024$.
(5) $4AgCl : Cr_2O_3 : 100 : 26.620 \pm .0052$.
(6) Percentage Cr_2O_3 in $Cr_2(SO_4)_3$, 38.799±.0092.
(7) $3AgCl : CrCl_3 :: 100 : 36.842 \pm .0031$.
(8) $2KClO_3 : K_2Cr_2O_7 :: 100 : 120.216 \pm .0235$.
(9) Percentage Cr_2O_3 in $Ag_2CrO_4.4NH_3$, 19.059±.0074.
(10) $2AgCl : Ag_2CrO_4.4NH_3 :: 100 : 139.357 \pm .1109$.
(11) Percentage Cr_2O_3 in $Am_2Cr_2O_7$, 60.337±.0029.
(12) $Ag_2CrO_4 : 3I :: 100 : 114.630 \pm .015$.
(13) $Ag_2CrO_4.4NH_3 : 3I :: 100 : 95.208 \pm .0497$.
(14) $2K_2Cr_2O_7 : KHI_2O_6 :: 100 : 66.212 \pm .0044$.
(15) $2Am_2Cr_2O_7 : KHI_2O_6 :: 100 : 77.268 \pm .0041$.
(16) $2AgBr : Ag_2CrO_4 :: 100 : 88.334 \pm .0009$.
(17) $2AgBr : Ag_2Cr_2O_7 :: 100 : 114.962 \pm .0008$.

To reduce these we have the following atomic weights:

Ag = 107.880±.00016	S = 32.0650±.00012
Cl = 35.4605±.00011	N = 14.0081±.00008
Br = 79.9228±.00015	K = 39.0975±.00011
I = 126.926±.00023	H = 1.0078±.00001

[1] Journ. Amer. Chem. Soc., 31, 541. 1909.

Hence,

From ratio—

10	Cr=51.624±.3180
4	52.003±.0035
3	52.014±.0067
17	52.022±.0015
16	52.028±.0033
7	52.048±.0134
13	52.097±.2088
2	52.104±.0824
1	52.111±.0063
11	52.111±.0066
15	52.130±.0067
6	52.137±.0167
14	52.140±.0098
8	52.237±.0288
9	52.265±.0304
5	52.315±.0149
12	52.420±.0440
General mean	Cr=52.036±.0012

In this combination the work of Baxter and his colleagues carries overwhelming weight, and yet the work of Siewert, Baubigny, Rawson, and, in part, Meineke's is not entirely ignored. The high values, with their large probable errors, practically vanish from the general mean.

MOLYBDENUM.

If we leave out of account the inaccurate determination made by Berzelius,[1] we shall find that the data for the atomic weight of molybdenum lead to two independent estimates of its value—one near 92, the other near 96. The earlier results found by Berlin and by Svanberg and Struve lead to the lower number; the more recent investigations, together with considerations based upon the periodic classification, point conclusively to the higher.

The earliest investigation which we need especially to consider is that of Svanberg and Struve.[2] These chemists tried a variety of different methods, but finally based their conclusions upon the two following: First, molybdenum trioxide was fused with potassium carbonate, and the carbon dioxide which was expelled was estimated; secondly, molybdenum disulphide was converted into the trioxide by roasting, and the ratio between the weights of the two substances was determined.

By the first method it was found that 100 parts of MoO_3 will expel the following quantities of CO_2:

31.4954
31.3749
31.4705

Mean, 31.4469±.0248

The carbon dioxide was determined simply from the loss of weight when the weighed quantities of trioxide and carbonate were fused together. It is plain that if, under these circumstances, a little of the trioxide should be volatilized, the total loss of weight would be slightly increased. A constant error of this kind would tend to make the atomic weight of molybdenum too low.

By the second method, the conversion by roasting of MoS_2 into MoO_3, Svanberg and Struve obtained these results. Two samples of artificial disulphide were taken, A and B, and yielded for each hundred parts the following of trioxide:

89.7919 } A
89.7291 }

[1] Poggend. Annalen, 8, 1. 1826.

[2] Journ. prakt. Chem., 44, 301. 1848.

89.6436
89.7082
89.7660 } B
89.7640
89.8635

Mean, 89.7523±.0176

Three other experiments in series B gave divergent results, and, although published, are rejected by the authors themselves. Hence, it is not necessary to cite them in this discussion. We again encounter in these figures the same source of constant error which apparently vitiates the preceding series, namely, the possible volatilization of the trioxide. Here, also, such an error would tend to reduce the atomic weight of molybdenum.

From the CO_2 series..... Mo=91.93
From the MoS_2 series..... Mo=93.30

Berlin,[1] a little later than Svanberg and Struve, determined the atomic weight of molybdenum by igniting a molybdate of ammonium and weighing the residual MoO_3. Here, again, a loss of the latter by volatilization may (and probably does) lead to too low a result. The salt used was $(NH_4)_4Mo_5O_{17}.3H_2O$, and in it these percentages of MoO_3 were found:

81.589 81.558
81.612 81.555

Mean, 81.581±.0095

Hence, Mo=92.16.

Until 1859 the value 92 was generally accepted on the basis of the foregoing researches, but in this year Dumas[2] published some figures tending to sustain a higher number. He prepared molybdenum trioxide by roasting the disulphide, and then reduced it to metal by ignition in hydrogen. At the beginning the hydrogen was allowed to act at a comparatively low temperature, in order to avoid volatilization of trioxide; but at the end of the operation the heat was raised sufficiently to insure a complete reduction. From the weights I calculate the percentages of metal in MoO_3:

MoO_3.	*Mo.*	*Per cent.*
0.448	0.299	66.741
.484	.323	66.736
.484	.322	66.529
.498	.332	66.667
.559	.373	66.726
.388	.258	66.495

Mean, 66.649±.030

Hence, Mo=95.924.

In 1868 the same method was employed by Debray.[3] His trioxide was purified by sublimation in a platinum tube. His data are as follows:

MoO_3.	*Mo.*	*Per cent.*
5.514	3.667	66.503
7.910	5.265	66.561
9.031	6.015	66.604

Mean, 66.556±.020

Hence, Mo=95.524.

For the same ratio we have also a single experiment by Rammelsberg,[4] who, closely following Dumas' method, found in molybdenum trioxide 66.708 per cent of metal. As this figure falls within the limits of Dumas' series, we may assign it equal weight with one experiment in the latter.

Debray also made two experiments upon the precipitation of molybdenum trioxide in ammoniacal solution by nitrate of silver. In his results, as published, there is curious discrep-

[1] Journ. prakt. Chem., 49, 444. 1850.
[2] Ann. Chem. Pharm., 105, 84; and 113, 23.
[3] Compt. Rend., 66, 734.
[4] Berlin Monatsbericht, 1877, p. 574.

ancy, which, I have no doubt, is due to a typographical error. These results I am therefore compelled to leave out of consideration. They could not, however, exert a very profound influence upon the final discussion.

In 1873, Lothar Meyer [1] discussed the analyses made by Liechti and Kemp [2] of four chlorides of molybdenum, and in the first edition of this work the same data were considered in detail. The analyses, however, were not intended as determinations of atomic weight, and since good determinations have been more recently published, the work on the chlorides will be omitted from further consideration. It is enough to state here that they gave values for Mo ranging near 96, both above and below that number, with an extreme range of over eight-tenths of a unit.

In 1893 the determinations by Smith and Maas appeared,[1] representing an entirely new method. Sodium molybdate, purified by many recrystallizations and afterwards dehydrated, was heated in a current of pure, dry, gaseous hydrochloric acid. The compound $Mo_3O.2HCl$ was thus distilled off, and the sodium molybdate was quantitatively transformed into sodium chloride. The latter salt was afterwards carefully examined, and proved to be free from molybdenum. The data, with all weights reduced to a vacuum standard, are subjoined:

Na_2MoO_4.	*NaCl.*	*Per cent NaCl.*
1.14726	0.65087	56.733
.89920	.51023	56.743
.70534	.40020	56.739
.70793	.40182	56.760
1.26347	.71695	56.745
1.15217	.65367	56.734
.90199	.51188	56.750
.81692	.46358	56.747
.65098	.36942	56.748
.80563	.45717	56.747
		Mean, 56.745±.0017

Hence, Mo = 96.040.

In 1895, Seubert and Pollard [5] determined the atomic weight of molybdenum by two methods. First, the carefully purified trioxide, in weighed amounts, was dissolved in an excess of a standard solution of caustic soda. This solution was standardized by means of hydrochloric acid, which in turn had been standardized gravimetrically as silver chloride. Hence, indirectly, the ratio $2AgCl : MoO_3$ was measured. Sulphuric acid and lime water were also used in the titrations, so that the entire process was rather complicated. Ignoring the intermediate data, the end results, in weights of MoO_3 and AgCl, were as follows. The third column gives the MoO_3 proportional to 100 parts of AgCl:

MoO_3.	*AgCl.*	*Ratio.*
3.6002	7.1709	50.206
3.5925	7.1569	50.196
3.7311	7.4304	50.214
3.8668	7.7011	50.211
3.9361	7.8407	50.201
3.8986	7.7649	50.208
3.9630	7.8941	50.202
3.9554	7.8806	50.192
3.9147	7.7999	50.189
3.8543	7.6767	50.208
3.9367	7.8437	50.190
		Mean, 50.202±.0018

Hence, Mo = 95.92.

The second method adopted by Seubert and Pollard was the old one of reducing the trioxide to metal by heating in a current of hydrogen. The weights and percentages of metal are subjoined:

[1] Ann. Chem. Pharm., 169, 365. 1873.
[2] Ann. Chem. Pharm., 169, 344.
[3] Journ. Amer. Chem. Soc., 15, 397. 1893.
[5] Zeitsch. anorg. Chem., 8, 434. 1895.

MoO_3.	Mo.	Per cent.
1.8033	1.2021	66.661
1.9345	1.1564	66.670
3.9413	2.6275	66.666
1.5241	1.0160	66.662
4.0533	2.7027	66.679
		Mean, 66.668±.0022

Hence, Mo = 96.006.

Vandenberghe [1] prepared molybdenum dibromide, which was next reduced to metal by heating in hydrogen. The metal was then oxidized to trioxide by means of nitric acid. The data are as follows:

Mo.	MoO_3.	Per cent Mo.
0.7143	1.0711	66.689
.3453	.5177	66.699
.9693	1.4533	66.696
.5089	.7631	66.689
1.7212	2.5820	66.689
		Mean, 66.692±.0015

Corrected to a vacuum this becomes 66.687±.0015.

Hence, Mo = 96.088.

The determinations of the atomic weight of molybdenum by Müller [2] are based upon the oxidation of the metal to MoO_3. The data, with vacuum weights, are as follows:

Mo.	MoO_3.	Per cent Mo.
0.52591	0.78879	66.673
.56327	.84487	66.669
1.12757	1.69117	66.674
.53014	.79517	66.670
1.10754	1.66130	66.667
1.62166	2.43181	66.686
1.45530	2.18259	66.678
.94968	1.42428	66.678
.65659	.9870	66.679
		Mean, 66.675±.0013

Hence, Mo = 96.036.

This mean may be combined with former determinations thus:

Dumas	66.649±.0300
Debray	66.556±.0200
Rammelsberg	66.708±.0680
Seubert and Pollard	66.668±.0022
Vandenberghe	66.687±.0015
Müller	66.675±.0013
General mean	66.679±.0009

Neglecting all determinations made before 1859, there are now three ratios from which to compute the atomic weight of molybdenum, as follows:

(1) $MoO_3 : Mo :: 100 : 66.679 \pm .0009$
(2) $2AgCl : MoO_3 :: 100 : 50.202 \pm .0018$
(3) $Na_2MoO_4 : 2NaCl :: 100 : 56.745 \pm .0017$

Reducing these with Ag = 107.880±.00016; Cl = 35.4605±.00011; and Na = 23.0029±.00012 we have—

From ratio—2	Mo=95.920±.0052
3	96.040±.0062
1	96.053±.0029
General mean	Mo=96.028±.0024

In this combination the actual uncertainty is greater than the decimals. For practical purposes the round number 96 can be used.

[1] Acad. Roy. Belge. Mém. Couronnés, T. 56.

[2] Journ. Amer. Chem. Soc. 37, 2046. 1915.

TUNGSTEN.

The atomic weight of tungsten has been determined from analyses of the trioxide, the hexchloride, and the tungstates of iron, silver, sodium, and barium.

The composition of the trioxide has been the subject of many investigations. Malaguti[1] reduced this substance to the blue oxide, and from the difference between the weights of the two compounds obtained a result now known to be considerably too high. In general, however, the method of investigation has been to reduce WO_3 to W in a stream of hydrogen at a white heat, and afterwards to reoxidize the metal, thus getting from one sample of material two results for the percentage of tungsten. This method is probably accurate, provided that the trioxide used be pure.

The first experiments which we need consider are, as usual, those of Berzelius.[2] 899 parts WO_3 gave, on reduction, 716 of metal. 676 of metal, reoxidized, gave 846 WO_3. Hence these percentages of W in WO_3:

79. 644 by reduction
79. 905 by oxidation

Mean, 79. 7745±. 0880

Hence, W = 189.324.

These figures are far too high, the error being probably due to the presence of alkaline impurity in the trioxide employed.

Next in order of time comes the work of Schneider,[3] who, with characteristic carefulness, took every precaution to get pure material. His percentages of tungsten are as follows:

Reduction series.

79. 336
79. 254
79. 312
79. 326
79. 350

Mean, 79. 3156

Oxidation Series.

79. 329
79. 324
79. 328

Mean, 79. 327
Mean of all, 79. 320±.0068

Hence, W = 184.108.

Closely agreeing with these figures are those of Marchand,[4] published in the following year:

Reduction Series.

79. 307
79. 302

Mean, 79. 3045

Oxidation Series.

79. 321
79. 352

Mean, 79. 3365
Mean of all, 79. 3205±.0073

Hence, W = 184.114.

[1] Journ. prakt. Chem., 8, 179. 1836.
[2] Poggend. Annalen, 8, 1. 1826.
[3] Journ. prakt. Chem., 50, 152. 1850.
[4] Ann. Chem. Pharm., 77, 261. 1851.

The figures obtained by v. Borch [1] agree approximately with the foregoing series. They are as follows:

Reduction Series.

79. 310
79. 212
79. 289
79. 313
79. 225
79. 290
79. 302
Mean, 79. 277

Oxidation Series.

79. 359
79. 339
Mean, 79. 349
Mean of all, 79. 293±.0108

Hence, W = 183.806.

Dumas [2] gives only a reduction series, based upon trioxide obtained by the ignition of a pure ammonium tungstate. The reduction was effected in a porcelain boat, platinum being objectionable on account of the tendency of tungsten to alloy with it. Dumas publishes only weighings, from which I have calculated the percentages:

WO_3	*W.*	*Per cent.*
2. 784	2. 208	79. 310
2. 994	2. 373	79. 259
4. 600	3. 649	79. 326
. 985	. 781	79. 289
. 917	. 727	79. 280
. 917	. 728	79. 389
1. 717	1. 362	79. 324
2. 988	2. 370	79. 317
	Mean,	79. 312±.009

Hence, W = 184.019.

The data furnished by Bernoulli [3] differ widely from those just given. This chemist undoubtedly worked with impure material, the trioxide having a greenish tinge. Hence the results are too high. Here are the percentages of W:

Reduction Series.

79. 556
79. 526
79. 553
79. 558
79. 549
78. 736
Mean, 79. 413

Oxidation Series.

79. 558
79. 656
79. 555
79. 554
Mean, 79. 581
Mean of all, 79. 480±.056

Hence, W = 185.918.

[1] Journ. prakt. Chem., 54, 254. 1851. [2] Ann. Chem. Pharm., 113, 23. 1860. [3] Poggend. Annalen, 111, 573. 1860.

Two reduction experiments by Persoz [1] give the following results:

WO_3	W.	Per cent.
1. 7999	1. 4274	79. 304
2. 249	1. 784	79. 324
		Mean, 79. 314±.007

Hence, W = 184.041.

Next in order is the work done by Roscoe.[2] This chemist used a porcelain boat and tube, and made six weighings, after successive reductions and oxidations, with the same sample of 7.884 grams of trioxide. These weighings give me the following five percentages which, for the sake of uniformity with foregoing series, I have classified under the usual, separate headings:

Reduction Series.

79. 196
79. 285
79. 308

Mean, 79. 263

Oxidation Series.

79. 230
79. 299

Mean, 79.2645

Mean of all, 79. 264±. 0146

Hence, W = 183.482.

In Waddell's experiments [3] especial precautions were taken to procure tungstic oxide free from silica and molybdenum. This oxide, elaborately purified, was reduced in hydrogen, with the following results:

WO_3.	W.	Per cent.
1. 4006	1. 1115	79. 359
. 9900	. 7855	79. 343
1. 1479	. 9110	79. 362
. 9894	. 7847	79. 311
4. 5639	3. 6201	79. 320
		Mean, 79. 339±. 0069

Hence, W = 184.332.

The investigation by Pennington and Smith [4] started from the supposition that the tungsten compounds studied by their predecessors had not been completely freed from molybdenum. Accordingly, tungstic oxide, carefully freed from all other impurities, was heated in a stream of gaseous hydrochloric acid, so as to volatilize all molybdenum as the compound $MoO_3.2HCl$. The residual WO_3, was then reduced in pure hydrogen, and the tungsten so obtained was oxidized in porcelain crucibles. Care was taken to exclude reducing gases, and the trioxide was finally cooled in vacuum desiccators over sulphuric acid. The oxidation data are as follows, with the usual percentage column added. The weights are reduced to a vacuum:

Tungsten.	Oxygen gained.	Percentage.
0. 862871	0. 223952	79. 394
. 650700	. 168900	79. 392
. 597654	. 155143	79. 390
. 666820	. 173103	79. 391
. 428228	. 111168	79. 390
. 671920	. 174406	79. 392
. 590220	. 153193	79. 394
. 568654	. 147588	79. 394
1. 080973	. 280600	79. 392
		Mean, 79. 392±. 0004

Hence, W = 184.92.

[1] Zeit. anal. Chem., 3, 260. 1864.
[2] Ann. Chem. Pharm., 162, 368. 1872.
[3] Amer. Chem. Journ., 8, 280. 1886.
[4] Read before the Amer. Philos. Soc., Nov. 2, 1894.

The very high value for tungsten found by Pennington and Smith, nearly a unit higher than that which was commonly accepted, seems to have at once attracted the attention of Schneider,[1] who criticized the paper somewhat fully, and gave some new determinations of his own. The tungsten trioxide employed in this new investigation was heated in gaseous hydrochloric acid, and the absence of molybdenum was proved. The data obtained, both by reduction and by oxidation, are as follows:

Reduction Series.

WO_3.	W.	Per cent.
2.0738	1.6450	79.323
4.0853	3.2400	79.309
6.1547	4.8811	79.307

Oxidation Series.

W.	WO_3.	Per cent.
1.5253	1.9232	79.311
3.1938	4.0273	79.304
4.7468	5.9848	79.314

Mean of all, 79.311±.0018

Hence, W = 184.007.

In order to account for the difference between this result and that of Pennington and Smith, an impurity in the molybdenum trioxide amounting to about 1 per cent would be necessary. Schneider suggests that the quantities of material used by Pennington and Smith were too small, and that there may have been mechanical loss of small particles during the long heatings. Such osses would tend to raise the atomic weight computed from the experiments. On the other hand, the losses could hardly have been uniform in extent, and the extremely low probable error of Pennington and Smith's series renders Schneider's supposition improbable. The error, if error exists, must be accounted for otherwise.

Soon after Schneider's paper appeared, another set of determinations by Shinn [2] was published from Smith's laboratory. Attempts to verify the results obtained by Smith and Desi having proved abortive, and other experiments having failed, Shinn resorted to the oxidation method and gives the subjoined data. The percentage column is added by myself:

W.	WO_3.	Per cent.
0.22297	0.28090	79.377
.17200	.21664	79.394
.10989	.13844	79.377
.10005	.12598	79.417

Mean, 79.391±.0066

Hence, W = 184.908.

This figure is very close to that found in Pennington and Smith's series.

The great discordance between the determinations so far cited, led Hardin [3] to a very careful investigation of tungsten trioxide. The substance was prepared from various sources, and manipulated by various methods; and although concordant results were sometimes obtained in succession, the discordance between different series of experiments was very great. Hardin therefore concluded that a discussion of his figures, with reference to the atomic weight of tungsten, would be useless. Nevertheless, partly for the sake of completeness, and partly because this calculation is in great measure a study of the compensation of errors, I prefer to cite Hardin's determinations, in order that they may be compared with others. For this purpose I give his 64 determinations as one series. The letters o and r indicate oxidation and reduction experiments, respectively.

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[1] Journ. prakt. Chem. (2), 53, 288. 1896.
[2] Thesis, University of Pennsylvania, 1896. "The atomic mass of tungsten."
[3] Journ. Amer. Chem. Soc., 19, 657. 1897.

The atomic weights found were as follows:

r 184. 05	r 184. 01	o 184. 86	o 184. 20
r 184. 04	r 184. 66	o 184. 27	r 183. 58
r 183. 98	r 183. 99	o 184. 07	r 183. 51
r 184. 33	r 183. 93	r 183. 83	r 183. 83
r 183. 94	r 183. 91	r 183. 80	o 184. 05
r 183. 91	o 184. 53	r 183. 67	o 184. 22
r 183. 66	o 184. 01	r 183. 56	o 184. 06
o 184. 94	o 184. 65	r 183. 72	r 184. 03
o 184. 86	r 183. 55	r 183. 71	r 183. 81
o 185. 00	r 184. 34	r 183. 80	o 183. 85
o 184. 91	r 184. 21	r 183. 87	o 184. 14
o 184. 75	r 183. 95	o 183. 83	r 183. 89
o 184. 15	o 183. 70	o 183. 75	r 183. 63
r 184. 88	o 184. 30	o 184. 13	o 184. 17
r 184. 85	o 183. 99	o 183. 90	o 184. 08
r 184. 94	o 184. 07	o 183. 82	r 134. 13

The mean of all is W = 184.105, ±.0337. This gives a percentage of W in WO_3 of 79.320, ±.0185. The discordances were shown by Hardin to be due partly to impurities in his material, such as nitrogen retained by trioxide prepared from ammonium tungstate, and partly to volatility of the oxide at high temperatures. In a later memoir [1] he discusses these errors at some length, and gives a few other determinations which are even more discordant, and therefore not worth citation now.

Taylor's thesis,[2] representing work done in Smith's laboratory, is essentially a study of errors. He found that constant weight could not be secured during reduction experiments with the trioxide, and he also found, like Hardin, that the oxidations generally gave the higher values for the atomic weight of tungsten. Furthermore, he ascertained that tungstic oxide derived from colloidal ammonium tungstate gave different values dependent upon whether the latter compound was dialyzed or undialyzed. Oxide from the dialyzed salt gave the highest atomic weights. Some of the discrepancies were ultimately traced to the presence in the material studied of a complex salt containing manganese and iron, and the influence of these impurities was studied. Iron, and also molybdenum, tend to lower the apparent atomic weight of tungsten; manganese, and in much greater measure, raises it. The errors are in opposite directions, but do not absolutely compensate one another.

One new method for measuring the atomic weight of tungsten was tested by Taylor, but the results were not satisfactory. Sodium carbonate was heated in a glass bulb with tungsten trioxide and water, the latter was distilled off after effervescence had ceased, and the residue was then heated to 300° in a vacuum. The weights of carbonate and oxide being known, the loss in weight represented carbon dioxide. The ratio between WO_3 and CO_2 was thus determined. I cite the weights, and also the values for the ratio $WO_3 : CO_2 :: 100 : x$:

Weight WO_3.	*Weight CO_2.*	*Ratio.*
2. 0802	0. 3952	18. 998
2. 1937	. 4173	19. 023
4. 0818	. 7762	19. 016
3. 3629	. 6394	19. 013
		Mean, 19. 0125 ± .0034

Hence, W = 183.44; a determination which Taylor regards as worthless, while admitting that the method is one of some promise.

Several of the investigations so far described were carried out under the direction of, or in cooperation with Prof. Edgar F. Smith. The experience obtained in their conduct gave a sound basis for further researches, which were undertaken by Smith and Exner.[3] These authors discuss at length the sources of error in former determinations of the atomic weight of tungsten,

[1] Journ. Amer. Chem. Soc., 21, 1017. 1899.
[2] Thesis, University of Pennsylvania, 1901. "Atomic weight of tungsten."
[3] Proc. Amer. Phil. Soc., 43, 123. 1904.

and point out the difficulty of preparing pure material, a difficulty which was at last overcome. From a pure ammonium tungstate they prepared pure tungsten, the pure trioxide, and pure tungsten hexchloride, free from oxychloride, and with these substances their atomic weight determinations were made. At this point only their syntheses of the trioxide will be considered, their other series being discussed later. Their figures, with vacuum weights, and the usual percentage column are given below:

Weight W.	*Weight WO_3.*	*Per cent.*
2.24552	2.83144	79.306
1.78151	2.24619	79.313
1.63590	2.06270	79.309
1.38534	1.74665	79.314
1.29903	1.63774	79.318
2.01302	2.53781	79.321
2.18607	2.75632	79.311
2.36755	2.98478	79.323
1.94958	2.45781	79.322
4.43502	5.59141	79.318
2.37603	2.99548	79.321
2.58780	3.26260	79.314
2.58503	3.25886	79.322
2.38298	3.00441	79.316
2.05578	2.59169	79.322
3.60828	4.54915	79.318
6.22621	7.84949	79.320
5.28444	6.66239	79.317
3.99095	5.03138	79.321
7.30166	9.20647	79.309
3.44143	4.33870	79.319
2.67709	3.37541	79.312
4.96735	6.26229	79.322
		Mean. 79.3169±.0007

Hence, W = 184.075, ±.0064.

There are still other analyses by Riche,[1] which are of no value for they give to tungsten an atomic weight of about ten units too low. We may, therefore, neglect his series and go on to combine the others:

1. Berzelius	79.7745	± .0880
2. Schneider, 1850	79.320	± .0068
3. Marchand	79.3205	± .0073
4. Borch	79.293	± .0108
5. Dumas	79.312	± .0090
6. Bernoulli	79.480	± .0560
7. Persoz	79.314	± .0070
8. Roscoe	79.264	± .0146
9. Waddell	79.339	± .0069
10. Pennington and Smith	79.392	± .0004
11. Schneider, 1896	79.311	± .0018
12. Shinn	79.391	± .0066
13. Hardin	79.320	± .0185
14. Smith and Exner	79.3169	± .0007
General mean	79.3706	± .00034

In this combination only two values carry much weight; the tenth and the fourteenth. The series by Pennington and Smith is evidently much overvalued, and exerts an undue influence upon the general mean. In reality the series by Smith and Exner is by far the most trustworthy of all, and the figures given by Schneider, Marchand, Dumas, and Persoz are in harmony with it. The other series are more doubtful. The weighted mean of twelve series, omitting Nos. 10 and 14, is 79.3160; a value almost identical with that of Smith and Exner. The latter, therefore, is abundantly confirmed.

[1] Ann. Chim. Phys., (3), 50, 11. 1857.

In 1861 Scheibler [1] deduced the atomic weight of tungsten from analyses of barium meta-tungstate, $BaO.4WO_3.9H_2O$. In four experiments he estimated the barium as sulphate, getting closely concordant results, which were, however, very far too low. These, therefore, are rejected. But from the percentage of water in the salt a better result was attained. The percentages of water are as follows:

13.053
13.054
13.045
13.010
13.022
Mean, 13.0368 ± .0060

Hence, W = 184.06.

The work of Zettnow,[2] published in 1867, was more complicated than any of the foregoing researches. He prepared the tungstates of silver and of iron, and from their composition determined the atomic weight of tungsten.

In the case of the iron salt the method of working was this: The pure, artificial $FeWO_4$ was fused with sodium carbonate, the resulting sodium tungstate was extracted by water, and the thoroughly washed residual ferric oxide was dissolved in hydrochloric acid. This solution was then reduced by zinc, and titrated for iron with potassium permanganate. Corrections were applied for the drop in excess of permanganate needed to produce distinct reddening, and for the iron contained in the zinc. 11.956 grammes of the latter metal contained iron corresponding to 0.6 cc. of the standard solution. The permanganate was standardized by comparison with pure ammonium-ferrous sulphate, $Am_2Fe(SO_4)_2.6H_2O$, so that, in point of fact, Zettnow establishes directly only the ratio between that salt and the ferrous tungstate. From Zettnow's four experiments in standardizing I find that 1 cc., of his solution corresponds to 0.0365457 gramme of the double sulphate, with a probable error of ±.0000012.

Three sets of titrations were made. In the first a quantity of ferrous tungstate was treated according to the process given above; the iron solution was diluted to 500 cc., and four titrations made upon 100 cc. at a time. The second set was like the first, except that three titrations were made with 100 cc. each, and a fourth upon 150 cc. In the third set the iron solution was diluted to 300 cc., and only two titrations upon 100 cc. each were made. In sets one and two thirty grammes of zinc were used for the reduction of each, while in number three but 20 grammes were taken. Zettnow's figures, as given by him, are quite complicated; therefore I have reduced them to a common standard. After applying all corrections the following quantities of tungstate, in grammes, correspond to 1 cc. of permanganate solution:

0.028301	First set
.028291	
.028311	
.028301	
.028367	Second set
.028368	
.028367	
.028367	
.028438	Third set
.028438	
Mean, .0283549 ± .0000115	

Hence, W = 184.40.

With the silver tungstate, Ag_2WO_4, Zettnow employed two methods. In two experiments the substance was decomposed by nitric acid, and the silver thus taken into solution was titrated with standard sodium chloride. In three others the tungstate was treated directly with common salt, and the residual silver chloride collected and weighed. Here again, on account of some complexity in Zettnow's figures, I am compelled to reduce his data to a common standard. To 100 parts of AgCl the following quantities of Ag_2WO_4 correspond:

[1] Journ. prakt. Chem., 83, 324.
[2] Poggend. Annalen, 130, 30.

By First Method.

161.665
161.603
Mean, 161.634±.021

By Second Method.

161.687
161.651
161.613
Mean, 161.650±.014
General mean from both series, 161.645±.012

Hence, W = 183.64.

For tungsten hexchloride we have first, two analyses by Roscoe, published in the same paper with the results upon the trioxide. In one experiment the chlorine was determined as AgCl; in the other the chloride was reduced by hydrogen, and the residual tungsten estimated. By bringing both results into one form of expression we have for the percentage of chlorine in WCl_6:[1]

53.610
53.632
Mean, 53.621±.0074

Hence, W = 184.03.

The investigation of tungsten hexchloride by Smith and Exner was much more elaborate. They prepared the substance from scrupulously pure materials, and further purified it by repeated sublimations. They decomposed the chloride by means of water, and weighed the residual tungsten trioxide. Their figures, with vacuum weights, are as follows, with a percentage column added by myself:

Weight WCl_6.	*Weight WO_3.*	*Per cent WO_3.*
3.18167	1.86085	58.487
2.66612	1.55903	58.476
3.52632	2.06244	58.487
1.52117	.88972	58.489
1.22299	.71523	58.482
2.28445	1.33603	58.484
3.25404	1.90337	58.493
3.37078	1.97133	58.483
7.76488	4.54082	58.479
2.08764	1.22114	58.494
2.80141	1.63859	58.492
3.24328	1.89681	58.484
4.97475	2.91262	58.489
3.04036	1.77838	58.492
4.31046	2.52133	58.493
3.21201	1.29381	58.490
2.70368	1.58135	58.489
3.60658	2.10934	58.486
2.63037	1.53835	58.484
3.41668	1.99808	58.480
3.49940	2.04675	58.489
3.86668	2.26145	58.486
3.40202	1.98970	58.486
3.20661	1.87533	58.483
3.26386	1.90909	58.492
6.73833	3.94031	58.476
7.37889	4.31643	58.497
		Mean, 58.4868±.0007

Hence, W = 184.14.

[1] The actual figures are as follows:
19.5700 grm. WCl_6 gave 42.4127 grm. AgCl.
10.4326 grm. WCl_6 gave 4.8374 grm. tungsten.

The syntheses of WO_3 by Smith and Exner give $W = 184.007 \pm .0079$. If we substitute that value in the hexchloride ratio we can compute an independent figure for the atomic weight of chlorine, namely, $Cl = 35.454 \pm .0028$. This figure is fairly good, and furnishes additional corroboration of Smith and Exner's determinations.

Smith and Exner also made a series of determinations of Taylor's ratio between WO_3 and CO_2. Their figures, with the ratio added, are as follows:

Weight WO_3.	*Weight CO_2.*	*Ratio.*
2.45645	0.46775	19.041
2.72292	.51785	18.974
3.32953	.63288	19.008
3.97620	.75473	18.981
3.44944	.65489	18.985
3.41273	.64796	18.986
6.10309	1.16087	19.021
6.39735	1.21644	19.015
2.17450	.41332	19.008
1.57903	.29966	18.977
		Mean, 18.9996 ± .0046

Hence, $W = 183.60$.

Combined with Taylor's mean, $19.0125 \pm .0034$, the general mean is $19.0073 \pm .0027$. This ratio, however, is affected by constant errors, as Smith and Exner have shown. There is not only a possibility of action of the sodium carbonate upon the glass bulb, but also a loss due to slight decomposition of the carbonate itself at the temperature employed in the experiments. Smith and Exner therefore discard the method as too inaccurate.

The work done by Smith and Desi [1] probably ought to be considered in connection with that of Pennington and Smith on the trioxide. Smith and Desi started with tungsten trioxide, freed from molybdenum by means of gaseous hydrochloric acid. This material was reduced in a stream of carefully purified hydrogen, and the water formed was collected in a calcium chloride tube and weighed. To the results found I add the percentage of water obtained from 100 parts of WO_3. Vacuum weights are given:

WO_3.	*H_2O.*	*Per cent H_2O.*
0.983024	0.22834	23.228
.998424	.23189	23.226
1.008074	.23409	23.221
.911974	.21184	23.229
.997974	.23179	23.226
1.007024	.23389	23.226
		Mean, 23.226 ± .0008

Hence, $W = 184.70$. This method is also criticized by Smith and Exner, and rejected.

Still another method for determining the atomic weight of tungsten was tested by Thomas,[2] also in Smith's laboratory. Sodium tungstate, $Na_2WO_4.2H_2O$, was dehydrated between 180° and 200°, and the percentage of water so determined. In this series of experiments the tungstate contained traces of carbonate and silicate. With purer material other determinations were made between 268° and 295°, and these were divided by the author into two series. I give below the percentage of water computed from Thomas's weights:

Preliminary.	*First series.*	*Second series.*
10.920	10.895	10.918
10.919	10.886	10.971
10.941	10.900	10.800
10.931	10.894	10.926
10.937	10.861	10.860
10.929	10.891	
10.926	10.878	Mean, 10.895 ± .0200
10.945		
10.924	Mean, 10.886 ± .0034	
10.935		
Mean, ± 10.931 .0020		

[1] Read before Amer. Phil. Soc., Nov. 2, 1894.

[2] Journ. Amer. Chem. Soc. 21, 373. 1899. Thomas cites some work on tungsten trioxide, but his figures appear in Hardin's series.

The general mean of the three series is $10.919 \pm .0017$. Hence W = 183.95, but with a very wide range of values in the individual experiments. This method, again, is rejected by the author himself as unsuited to exact atomic weight determinations.

The ratios, good and bad, rejecting nothing, from which to calculate the atomic weight of tungsten are now as follows:

(1) $WO_3 : W :: 100 : 79.3706 \pm .00034$
(2) $BaW_4O_{13}. 9H_2O : 9H_2O :: 100 : 13.0368 \pm .0060$
(3) $WO_3 : 3H_2O :: 100 : 23.226 \pm .0008$
(4) $Am_2Fe(SO_4)_2. 6H_2O : FeWO_4 :: 0.0365457 \pm .0000012 : 0.0283549 \pm .0000115$
(5) $2AgCl : Ag_2WO_4 :: 100 : 161.645 \pm .012$
(6) $WCl_6 : 6Cl :: 100 : 53.621 \pm .0074$
(7) $WCl_6 : WO_3 :: 100 : 58.4868 \pm .0007$
(8) $WO_3 : CO_2 :: 100 : 19.0073 \pm .0027$
(9) $Na_2WO_4.2H_2O : 2H_2O : 2H_2O :: 100 : 10.919 \pm .0017$

The values to use in reducing these ratios are:

Ag = 107.880 ± .00016	C = 12.0025 ± .00019
Cl = 35.4605 ± .00011	Na = 23.0029 ± .00012
S = 32.0650 ± .00012	Ba = 137.358 ± .0023
N = 14.0081 ± .00008	Fe = 55.880 ± .0012

H = 1.0078 ± .00001

Hence,

From ratio—	
8	W = 183.503 ± .0329
5	183.645 ± .0345
9	183.949 ± .0514
6	184.027 ± .0388
2	184.060 ± .1172
7	184.136 ± .0067
4	184.401 ± .1236
1	184.678 ± .0031
3	184.700 ± .0080
General mean	W = 184.582 ± .0026

This combination is evidently of very little significance. It includes data which are confessedly defective, and which do not tend to compensation of errors. The abnormally high value derived from ratio 1, which dominates the combination, is due to the excessive weight given to the determinations by Pennington and Smith, which Smith himself has discarded. If, in place of ratio 1 we take the determinations of Smith and Exner alone, namely, WO_3: W::100: 79,3169 ± .0007, we have the more trustworthy value, W = 184.075 ± .0064. This, combined with the value from ratio 7, also due to Smith and Exner, gives a general mean of W = 184.101, ± .0049. This seems to be the most probable value now available, and it is checked by the fact, already pointed out, that the two ratios of Smith and Exner, combined, give a good value for the atomic weight of chlorine.

URANIUM.

The earlier attempts to determine the atomic weight of uranium were all vitiated by the erroneous supposition that uranous oxide was really the metal. The supposition, of course, does not affect the weighings and analytical data which were obtained, although these, from their discordance with each other and with later and better results, have now only a historical value.

For present purposes the determinations made by Berzelius,[1] by Arfvedson,[2] and by Marchand [3] may be left quite out of account. Berzelius employed various methods, while the others relied upon estimating the percentage of oxygen lost upon the reduction of U_3O_8 to UO_2. Rammelsberg's [4] results also, although very suggestive, need no full discussion. He

[1] Schweigg. Journ., 22, 336. 1818. Poggend. Annalen, 1, 359. 1825.
[2] Poggend. Annalen, 1, 245. Berz. Jahr., 3, 120. 1822.
[3] Journ. prakt. Chem., 23, 497. 1841.
[4] Poggend. Annalen, 55, 318, 1842; 56, 125, 1842; 59, 9, 1843; 66, 91, 1845. Journ. prakt. Chem., 29, 324.

analyzed the green chloride, UCl_4; effected the synthesis of uranyl sulphate from uranous oxide; determined the amount of residue left upon the ignition of the sodio and bario-uranic acetates; estimated the quantity of magnesium uranate formed from a known weight of UO_2, and attempted also to fix the ratio between the green and the black oxides. His figures vary so widely that they could count for little in the establishing of any general mean; and, moreover, they lead to estimates of the atomic weight which are mostly below the true value. For instance, 12 lots of U_3O_8 from several different sources were reduced to UO_2 by heating in hydrogen. The percentages of loss varied from 3.83 to 4.67, the mean being 4.121. These figures give values for the atomic weight of uranium ranging from 185.74 to 235.84, or, in mean, 216.17. Such discordance is due partly to impurity in some of the material studied, and illustrates the difficulties inherent in the problem to be solved. Some of the uranoso-uranic oxide was prepared by calcining the oxalate and retained an admixture of carbon. Many such points were worked up by Rammelsberg with much care, so that his papers should be scrupulously studied by any chemist who contemplates a redetermination of the atomic weight of uranium.

In 1841 and 1842 Peligot published some data [1] showing that the atomic weight of uranium must be somewhere near 240. A few years later the same chemist published fuller data concerning the constant in question, but in the time intervening between his earlier and his final researches other determinations were made by Ebelmen and by Wertheim. These investigations we may properly discuss in chronological order. For present purposes the early work of Peligot may be dismissed as only preliminary in character. It showed that what had been previously regarded as metallic uranium was in reality an oxide, but gave figures for the atomic weight of the metal which were merely approximations.

Ebelmen's [2] determinations of the atomic weight of uranium were based upon analyses of uranic oxalate. This salt was dried at 100°, and then, in weighed amount, ignited in hydrogen. The residual uranous oxide was weighed, and in some cases converted into U_3O_8 by heating in oxygen. The following weights are reduced to a vacuum:

10.1644 grm. oxalate	gave	7.2939 grm. UO_2.			
12.9985	"	9.3312	"	Gain on oxidation,	.3685.
11.8007	"	8.4690	"	"	.3275.
9.9923	"	7.1731	"	"	.2812.
11.0887	"	7.9610	"	"	.3105.
10.0830	"	7.2389	"		
6.7940	"	4.8766	"		
16.0594	"	11.5290	"	"	.4531.

Reducing these figures to percentages, we may present the results in two columns. Column A gives the percentages of UO_2 in the oxalate, while B represents the amount of U_3O_8 formed from 100 parts of UO_2:

A.	*B.*
71. 924	.....
71. 787	103. 949
71. 767	103. 867
71. 621	103. 920
71. 794	103. 900
71. 793	.....
71. 778	.....
71. 790	103. 930
Mean, 71. 782±. 019	Mean, 103. 913±. 009

Hence U = 237.70. Hence U = 240.25

Wertheim's [3] experiments were even simpler in character than those of Ebelmen. Sodio-uranic acetate, carefully dried at 200°, was ignited, leaving the following percentages of sodium uranate:

[1] Compt. Rend., 12, 735. 1841. Ann. Chim. Phys. (3), 55. 1842.
[2] Journ. prakt. Chem., 27, 385. 1842.
[3] Journ. prakt. Chem., 29, 209. 1843.

67.51508
67.54558
67.50927

Mean, 67.52331±.0076

Hence U=239.28.

The final results of Peligot's[1] investigations appeared in 1846. Both the oxalate and the acetate of uranium were studied and subjected to combustion analysis. The oxalate was scrupulously purified by repeated crystallizations, and thirteen analyses, representing different fractions, were made. Seven of these gave imperfect results, due to incomplete purification of the material; six only, from the later crystallizations, need to be considered. In these the uranium was weighed as U_3O_8, and the carbon as CO_2. From the ratio between the CO_2 and U_3O_8 the atomic weight of uranium may be calculated without involving any error due to traces of moisture possibly present in the oxalate. I subjoin Peligot's weighings, and give, in the third column, the U_3O_8 proportional to 100 parts of CO_2:

CO_2.	*U_3O_8.*	*Ratio.*
1.456	4.649	319.299
1.369	4.412	322.279
2.209	7.084	320.688
1.019	3.279	321.786
1.069	3.447	322.461
1.052	3.389	322.148
		Mean, 321.443±.338

Hence U=240.22.

From the acetate, $UO_2(C_2H_3O_2)_2.2H_2O$, the following percentages of U_3O_8 were obtained:

Acetate.	*U_3O_8.*	*Per cent.*
5.061	3.354	66.2715
4.601	3.057	66.4421
1.869	1.238	66.2386
3.817	2.541	66.5706
10.182	6.757	66.3622
4.393	2.920	66.4694
2.868	1.897	66.1437
		Mean, 66.3569±.038

Hence, U=239.73.

The acetate also yielded the subjoined percentages of carbon and of water. Assuming that the figures for carbon were calculated from known weights of dioxide, with C=12 and O=16, I have added a third column, in which the carbon percentages are converted into percentages of CO_2:

H_2O.	*C.*	*CO_2.*
21.60	11.27	41.323
21.16	11.30	41.433
21.10	11.30	41.433
21.20	11.10	40.700
Mean, 21.265±.187	Mean, 11.24	Mean, 41.222±.092

From these data we get the following values for the molecular weight of uranyl acetate:

From percentage of U_3O_8	425.827± .1678
From percentage of CO_2	426.993± .9530
From percentage of H_2O	423.603±3.7250
General mean	425.861± .1651

Hence, U=239.77.

In the posthumous paper of Zimmermann, edited by Krüss and Alibegoff,[2] the atomic weight of uranium is determined by two methods. First, UO_2, prepared by several methods, is con-

[1] Compt. Rend., 22, 487. 1846.

[2] Ann. Chem., 232, 209. 1886.

verted into U_3O_8 by heating in oxygen. To begin with, U_3O_8 was prepared, and reduced to UO_2 by ignition in hydrogen. When the reduction takes place at moderate temperatures, the UO_2 is somewhat pyrophoric, but if the operation is performed over the blast lamp this difficulty is avoided. After weighing the UO_2, the oxidation is effected, and the gain in weight is observed. The preliminary U_3O_8 was derived from the following sources: A, from uranium tetroxide; B, from the oxalate; C, from uranyl nitrate; D, by precipitation with mercuric oxide. The full data, lettered as indicated above, are subjoined:

	UO_2.	U_3O_8.	*Per cent Uranate.*
A	8.9363	9.2872	3.927
	7.9659	8.2789	3.929
	12.4385	12.9270	3.927
B	12.8855	13.3913	3.925
	5.7089	5.9331	3.927
	9.6270	10.0051	3.928
C	13.1855	13.7036	3.929
	9.9973	10.3901	3.929
D	15.8996	16.5242	3.928
	7.4326	7.7245	3.927
			Mean, 3.9276±.0003
			Ebelmen found, 3.913±.009
			General mean, 3.9276±.0003

In short, Ebelmen's mean vanishes when combined with Zimmermann's. From Zimmermann's mean U = 239.58.

Zimmermann's second method was essentially that of Wertheim, namely, the ignition of the double acetate $UO_2(C_2H_3O_2)_2.NaC_2H_3O_2$, the residue being sodium uranate, $Na_2U_2O_7$.

Double Acetate.	*Uranate.*	*Per cent Uranate.*
4.272984	2.886696	67.557
5.272094	3.560770	67.540
2.912283	1.976428	67.556
3.181571	2.149309	67.555
		Mean, 67.552±.0027
		Werthelm found, 67.523±.0076
		General mean, 67.549±.0025

From Zimmermann's figures U = 239.69.

An entirely different method for determining the atomic weight of uranium was adopted by Aloy.[1] Pure uranyl nitrate was ignited in a suitable apparatus, and the nitrogen evolved was collected and measured. The residual green oxide of uranium was reduced to uranous oxide, which was weighed. From this weight and that of the nitrogen, as computed from its volume the atomic weight of the metal was calculated. Unfortunately, Aloy gives only the volumes of gas and the corresponding atomic weight, but not the weight of the oxide. His data, therefore, as published, are radically defective. Assuming N = 14.04, Aloy gives the following values for uranium:

239.3	239.4
239.4	239.5
239.6	239.4
239.3	239.4
Mean, 239.412±.0235	

If N = 14.0081, this reduces to U = 238.87.

The important memoir by Richards and Merigold [2] begins with a careful criticism of former determinations. In regard to Aloy's work, they show that the residual oxide probably contained some unexpelled nitrogen, and they also point out the difficulty of exactly measuring small volumes of gas. Their own work was based upon careful analyses of uranous bromide

[1] Ann. Chim. Phys. (7), 24, 418. Preliminary paper in Compt. Rend., 182, 551. 1901.

[2] Proc. Amer. Acad., 37, 365. 1902.

by the best established methods, and their results, with vacuum weights, are as follows. First, analyses to determine the ratio $4AgBr:UBr_4$:

Preliminary Series.

Weight UBr_4.	*Weight AgBr.*	*Ratio.*
2.2058	2.9699	74.272
1.4418	1.9401	74.316
1.4050	1.8910	74.299
1.1749	1.5818	74.276
		Mean, 74.291±.0070

Second Series.

Weight UBr_4.	*Weight AgBr.*	*Ratio.*
1.7999	2.4226	74.296
1.0662	1.4352	74.290
1.8551	2.4967	74.302
		Mean, 74.296±.0029

General mean of both series, 74.295±.0027. Hence, U=238.431.

Second, measurements of the ratio $4Ag : UBr_4$:

Weight UBr_4.	*Weight Ag.*	*Ratio.*
1.7999	1.3918	129.322
1.0662	.8245	129.315
1.8551	1.4342	129.347
		Mean, 129.328±.0066

Hence, U=239.395.

The two ratios, combined, give the cross ratio Ag : Br :: 100 : 74.074.

Oechsner de Coninck,[1] in order to establish the molecular weight of uranyl oxide, reduced UO_2Br_2 by heating. His results were as follows:

UO_2Br_2.	*UO_2.*	*Per cent UO_2.*
0.737	0.466	63.229
.900	.566	62.889
.720	.452	62.778
.818	.519	63.447
1.080	.681	63.056
		Mean, 63.080±.0805

Hence, U=241.1.

In a second brief paper[2] he gives three reductions of the chloride, UO_2Cl_2, by heating in hydrogen:

UO_2Cl_2.	*UO_2.*	*Per cent UO_2.*
0.523	0.414	79.159
.5763	.456	79.098
1.048	.830	79.198
		Mean, 79.152±.0197

Hence, U=237.24.

In 1911 and 1912 Oechsner de Coninck[3] published four more notes on the atomic weight of uranium, which can be summarized very briefly. First, there is a new series of reductions of $UOCl_2$ to UO_2.

UO_2Cl_2.	*UO_2.*	*Per cent UO_2.*
0.512	0.4053	79.160
1.022	.808	79.044
.358	.283	79.050
.092	.0727	79.022
.277	.2192	79.134
		Mean, 79.082±.0184

Hence, U=236.10.

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[1] Bull. Acad. Belg., Classe des Sciences, 1907, 1041.

[2] Ibid., 1908, 163. In another paper, Compt. Rend., 147, 1477, Oechsner de Coninck describes attempts to determine the atomic weight of chlorine by reductions of UO_2Cl_2. His results have no value and need not be considered here.

[3] Compt. Rend., 152, 711, 1179; 153, 63; 155, 1511.

Second. Uranic monohydrate was similarly reduced to UO_2.

$UO_3.H_2O$.	UO_2.	Per cent UO_2.
0.5326	0.4735	88.903
.5865	.5215	88.917
.4263	.3788	88.858
.4613	.410	88.879
.4163	.370	88.878
		Mean, 88.887±.0070

Hence, U = 240.07.

Third. Reduction of uranic dihydrate to UO_2.

$UO_3.2H_2O$.	UO_2.	Per cent UO_2.
0.6555	0.55	83.905
.5483	.46	83.896
.3658	.3066	83.816
.4528	.380	83.922
.5550	.465	83.784
		Mean, 83.865±.0183

Hence, U = 238.45.

Fourth. Calcination of uranium oxalate to UO_2.

$UO_2C_2O_4$.	UO_2.	Per cent UO_2.
0.3300	0.2490	75.455
.2639	.1991	75.445
.2903	.2190	75.439
.2900	.2188	75.448
.1453	.1096	75.430
.3299	.2489	75.447
.3961	.2989	75.461
		Mean, 75.446±.0026

Hence, U = 238.41.

These determinations by Oechsner de Coninck are evidently of no real value. They are given without adequate details as to purity of materials or methods of manipulation, the weights are carried in some cases only to the nearest milligramme, and with no attempt at vacuum corrections. The figures are given here as part of the published record, but only the last one will be utilized in the final reductions.

The determinations by Lebeau [1] are based upon the careful heating of uranyl nitrate, $UO_2(NO_3)_2.2H_2O$, and its reduction to UO_2. His weights follow, with a percentage column added.

Nitrate.	UO_2.	Per cent UO_2.
0.9657	0.6067	62.825
1.6038	1.0077	62.832
1.8226	1.1451	62.828
2.1934	1.3783	62.839
2.7473	1.7262	62.833
2.9402	2.4755	62.827
		Mean, 62.831±.0014

Hence U = 238.55.

The most elaborate determinations of the atomic weight of uranium were made by Hönigschmid; first by himself alone, and later in association with Miss Horovitz. In both cases uranium bromide was analyzed by the standard method, with all the precautions to insure accuracy that have been developed in recent times. In his first memoir [2] two series of analyses are given, as follows:

Series 1.

UBr_4.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
3.4006	.....	4.57930	.....	74.248
3.91401	.....	5.27180	.....	74.246
4.52766	3.50286	6.09741	129.255	74.249
5.13497	3.97256	6.91566	129.261	74.251

[1] Compt. Rend., 155, 163. 1912.

[2] Zeitschr. Elektrochem., 20, 452. 1914.

UBr_4.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
3.73118	.....	5.02536	.....	74.247
4.68875	3.62849	6.31652	129.249	74.246
3.28480	2.54131	4.42400	129.256	74.249
3.91067	3.02567	5.26715	129.249	74.246
4.16254	3.22038	.....	129.246	.....
			Mean, 129.253±.0015	74.248±.00025

From the Ag ratio, U=238.07.
From the AgBr ratio, U=238.08.

Series 2.

UBr_4.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
2.89549	.....	3.89900	.....	74.262
2.82823	.....	3.80830	.....	74.265
3.95050	.....	5.31979	.....	74.260
3.57277	.....	4.81110	.....	74.259
3.91948	3.03190	5.27803	129.275	74.260
3.77074	2.91689	5.07761	129.268	74.262
4.31113	3.33505	5.80562	129.268	74.258
3.33325	.....	4.48823	.....	74.266
5.14622	3.98089	6.93002	129.273	74.260
5.05193	3.90789	6.80279	129.275	74.263
5.33502	4.12698	7.18387	129.272	74.264
4.84910	3.75106	6.52962	129.273	74.263
5.24735	4.05913	7.06581	129.273	74.264
4.56095	3.52825	6.14204	129.269	74.268
			Mean, 129.272±.0006.	74.2617±.00014.

From the Ag ratio, U=238.15.
From the AgBr ratio, U=238.18.

In their joint memoir Hönigschmid and Horovitz [1] give two more series of analyses of the bromide. In the first series, before analysis, the bromide was fused in an atmosphere of bromine vapor; in the second series it was fused in nitrogen.

Series 1.

UBr_4.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
4.65837	3.60418	6.27409	129.249	74.247
3.99404	3.09028	5.37994	129.245	74.239
4.59078	3.55214	6.18353	129.240	74.242
4.43275	3.42969	5.97038	129.246	74.240
			Mean, 129.245±.0013	74.242±.0012.

From the Ag ratio, U=238.04.
From the AgBr ratio, U=238.03.

Series 2.

UBr_4.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
5.28043	4.08466	7.11092	129.275	74.258
5.36124	4.14755	7.22023	129.263	74.253
5.90561	4.56818	7.95227	129.277	74.262
3.14043	2.42929	4.22884	129.273	74.262
4.40397	3.40682	5.93036	129.263	74.258
			Mean, 129.270±.0020	74.259±.0012

From the Ag ratio, U=238.14.
From the AgBr ratio, U=238.16.

These series combine with those of Richards and Merigold as follows:

Ratio 4Ag : UBr_4 : : 100 : x.

Richards and Merigold	129.328±.0066
Hönigschmid 1	129.253±.0015
Hönigschmid 2	129.272±.0006
Hönigschmid and Horovitz 1	129.245±.0013
Hönigschmid and Horovitz 2	129.270±.0020
General mean	129.267±.00049

[1] Monats. Chem., 37, 185. 1916.

Ratio $4AgBr : UBr_4 :: 100 : x$.

Richards and Merigold	74.295 ±.0027
Hönigschmid 1	74.248 ±.00025
Hönigschmid 2	74.2617±.00014
Hönigschmid and Horovitz 1	74.242 ±.0012
Hönigschmid and Horovitz 2	74.259 ±.0012
General mean	74.2582±.00012

The following ratios relative to the atomic weight of uranium are now available for discussion:

(1) $UO_2.C_2O_4 : UO_2 :: 100 : 75.446 \pm .0026$.
(2) $UO_2.C_2O_4.H_2O : UO_2 :: 100 : 71.782 \pm .019$.
(3) $6CO_2 : U_3O_8 :: 100 : 321.443 \pm .338$.
(4) Molecular weight of uranyl acetate, $425.861 \pm .1650$.
(5) $UO_2.Na(C_2H_3O_2)_3 : Na_2U_2O_7 :: 100 : 67.549 \pm .0025$.
(6) $UO_2(NO_3)_2.2H_2O : UO_2 :: 100 : 62.831 \pm .0014$.
(7) $N : U :: 14.04 : 239.412 \pm .0235$.
(8) $4Ag : UBr_4 :: 100 : 129.267 \pm .00049$.
(9) $4AgBr : UBr_4 :: 100 : 74.2582 \pm .00012$.
(10) $3UO_2 : U_3O_8 :: 100 : 103.9276 \pm .0003$.

To reduce these ratios we have—

Ag=107.880±.00016	N=14.0081±.00008
Br=79.9228±.00015	Na=23.0029±.00012
C=12.0025±.00019	H= 1.0078±.00001

Hence,

From ratio—	
2	U=237.699±.1951
8	238.132±.0023
9	238.146±.0013
1	238.409±.0223
6	238.546±.0117
7	238.868±.0235
10	239.582±.0207
5	239.654±.0279
4	239.773±.1651
3	240.218±.2975
General mean	238.155±.0011

This final mean is practically identical with the value derived from the work of Hönigschmid and his colleague on uranium bromide. All the other values vanish.

SELENIUM.

The atomic weight of this element was first determined by Berzelius,[1] who, saturating 100 parts of selenium with chlorine, found that 179 of chloride were produced. Hence, Se= 79.24. Further on these figures will be combined with similar results by Dumas.

We may omit, as unimportant for present purposes, the analyses of alkaline selenates made by Mitscherlich and Nitzsch,[2] and pass on to the experiments published by Sacc [3] in 1847. This chemist resorted to a variety of methods, some of which gave good results, while others were unsatisfactory. First, he sought to establish the exact composition of SeO_2, both by synthesis and by analysis. The former plan, according to which he oxidized pure selenium by nitric acid, gave poor results; better figures were obtained upon reducing SeO_2 with ammonium bisulphite and hydrochloric acid, and determining the percentage of selenium set free.

SeO_2	*Se.*	*Per cent.*
0. 6800	0. 4828	71. 000
3. 5227	2. 5047	71. 102
4. 4870	3. 1930	71. 161
		Mean, 71. 088±. 032

Hence, Se=78.68.

[1] Poggend. Annalen, 8, 1. 1826. [2] Poggend. Annalen, 9, 623. 1827. [3] Ann. Chim. Phys. (3), 21, 119.

In a similar manner Sacc also reduced barium selenite, and weighed the resulting mixture of barium sulphate and free selenium. This process gave discordant results, and a better method was found in calcining $BaSeO_3$ with sulphuric acid, and estimating the resulting quantity of $BaSO_4$. In the third column I give the amounts of $BaSO_4$ equivalent to 100 of $BaSeO_3$.

$BaSeO_3$.	*$BaSO_4$.*	*Ratio.*
0.5573	0.4929	88.444
.9942	.8797	88.383
.2351	.2080	88.473
.9747	.8621	88.448
		Mean, 88.437±.013

Hence, Se = 78.59.

Still other experiments were made with the selenites of silver and lead; but the figures were subject to such errors that they need no further discussion here.

A few years after Sacc's work was published, Erdmann and Marchand made with their usual care a series of experiments upon the atomic weight under consideration.[1] They analyzed pure mercuric selenide, which had been repeatedly sublimed and was well crystallized. Their method of manipulation has already been described in the chapter upon mercury. These percentages of Hg in HgSe were found:

71.726
71.731
71.741
Mean, 71.7327±.003

Hence, Se = 79.05.

The next determinations were made by Dumas,[2] who returned to the original method of Berzelius. Pure selenium was converted by dry chlorine into $SeCl_4$, and from the gain in weight the ratio between Se and Cl was easily deducible. I include Berzelius' single determination, which I have already cited, and give in a third column the quantity of chlorine absorbed by 100 parts of selenium:

Se.	*Cl.*	*Ratio.*
1.709	3.049	178.409
1.810	3.219	177.845
1.679	3.003	178.856
1.498	2.688	179.439
1.944	3.468	178.395
1.887	3.382	179.226
1.935	3.452	178.398
		179.000—Berzelius
		Mean, 178.696±.125

Dumas' figures alone give Se = 79.38.

The question may here be properly asked, Whether it would be possible thus to form $SeCl_4$, and be certain of its absolute purity? A trace of oxychloride, if simultaneously formed, would increase the apparent atomic weight of selenium. In point of fact, this method gives a higher value for Se than any of the other processes which have been adopted, and that value has the largest probable error of any one in the entire series. A glance at the table which summarizes the discussion at the end of this chapter will render this point sufficiently clear.

Still later, Ekman and Pettersson [3] investigated several methods for the determination of this atomic weight, and finally decided upon the two following:

First, pure silver selenite, Ag_2SeO_3, was ignited, leaving behind metallic silver, which, however, sometimes retained minute traces of selenium. The data obtained were as follows:

Ag_2SeO_3.	*Ag.*	*Per cent Ag.*
5.2102	3.2787	62.929
5.9721	3.7597	62.954

[1] Journ. prakt. Chem., 55, 202. 1852.
[2] Ann. Chem. Pharm., 113, 32. 1860.
[3] Ber. Deutsch. chem. Gesell., 9, 1210. 1876. Published in detail by the society at Upsala.

Ag_2SeO_3.	Ag.	Per cent Ag.
7. 2741	4. 5803	62. 967
7. 5390	4. 7450	62. 939
6. 9250	4. 3612	62. 978
7. 3455	4. 6260	62. 978
6. 9878	4. 3992	62. 955
		Mean, 62. 957±. 0048

Hence, Se = 78.95.

Secondly, a warm aqueous solution of selenious oxide was mixed with HCl and reduced by a current of SO_2. The reduced Se was collected upon a glass filter, dried, and weighed.

SeO_2.	Se.	Per cent Se.
11. 1760	7. 9573	71. 199
11. 2453	8. 0053	71. 185
24. 4729	17. 4232	71. 193
20. 8444	14. 8383	71. 187
31. 6913	22. 5600	71. 191
		Mean, 71. 191±. 0016

Hence$_2$ Se = 79.076.

Lenher,[1] in order to determine the atomic weight of selenium, studied two of its compounds. First, silver selenite was heated in a stream of gaseous hydrochloric acid, and so transfomed into silver chloride. In a second series of experiments the silver chloride was afterwards reduced to metal by heating in hydrogen. Two ratios were thus determined. For convenience I now treat the two series as one. Lenher's data, with vacuum weights, and with the corresponding percentages added by myself, are as follows:

Ag_2SeO_3.	AgCl.	Ag.	Per cent Ag.	Per cent AgCl.
0. 98992	0. 82715	.....	.....	83. 557
1. 59912	1. 33600	.....	.....	83. 560
2. 70573	2. 26087	.....	.....	83. 559
. 26204	. 21897	0. 16480	62. 891	83. 564
. 58078	. 48522	. 36534	62. 906	83. 546
. 70614	. 58999	. 44417	62. 901	83. 551
. 80811	. 67532	. 50821	62. 889	83. 568
. 98396	. 82232	. 61882	62. 891	83. 572
1. 29685	1. 08350	. 81562	62. 892	83. 549
1. 63103	1. 36288	1. 02588	62. 898	83. 559
2. 00162	1. 67234	1. 25884	62. 891	83. 549
			Mean, 62. 895±. 0014	83. 558±. 0017

From Ag ratio, Se = 79.288.

From AgCl ratio, Se = 79.332.

Secondly, ammonium bromoselenate was studied. From this salt the selenium was precipitated by hydroxylamine hydrochloride, and then collected and weighed in a Gooch crucible. The vacuum weights and percentages of selenium follow:

Am_2SeBr_6.	Se.	Per cent Se.
1. 00059	0. 13324	13. 3161
1. 50153	. 20022	13. 3344
2. 00059	. 26649	13. 3209
2. 00126	. 26657	13. 3201
3. 00125	. 39958	13. 3138
4. 00216	. 53346	13. 3293
5. 00218	. 66656	13. 3254
5. 03001	. 66998	13. 3196
		Mean, 13. 3224±. 0017

Hence, Se = 79.25.

[1] Journ. Amer. Chem. Soc., 20, 355. 1898. Thesis, University of Pennsylvania.

Steiner's [1] determinations, two in number, were made incidentally to his work on tellurium. Phenyl selenide was burned in a combustion tube, and the carbon dioxide so produced was weighed. To his figures I add the ratio $(C_6H_5)_2Se : 12CO_2 :: 100 : x$:

Selenide.	*CO_2.*	*Ratio.*
0.2812	0.6375	226.707
.5371	1.2158	226.365
		Mean, 226.536±.0485

Hence, Se=78.91. This determination is of trifling significance.

Julius Meyer [2] analyzed silver selenite electrolytically. The silver was precipitated from a solution of the salt in potassium cyanide. With vacuum weights the data are as follows:

Ag_2SeO_3.	*Ag.*	*Per cent Ag.*
0.5152	0.3241	62.907
.5237	.3295	62.915
1.6964	1.0672	62.910
1.8793	1.1826	62.928
2.1460	1.3503	62.922
		Mean, 62.9164±.0082

From the solutions 0.0002 gramme of silver was recovered, to be added to the sum of the silver weights given above. This raises the percentage to 62.9193. Hence, Se=79.155.

Combining Meyer's series with its predecessors we have—

Ekman and Pettersson	62.957 ±.0048
Lenher	62.895 ±.0014
Meyer	62.9193±.0082
General mean	62.9003±.0013

In order to determine the atomic weight of selenium Kužma and Křehlik [3] analyzed the dioxide SeO_2. This was first sublimed in a current of pure air, then dissolved in hydrochloric acid, and reduced to selenium by saturating the solution with sulphur dioxide and heating in a sealed bomb. The weights given are as follows, with a percentage column added.

SeO_2.	*Se.*	*Per cent Se.*
0.44245	0.31523	71.246
.61918	.44122	71.259
1.39106	.99109	71.247
.66740	.47544	71.238
.65154	.46414	71.237
.96042	.68417	71.237
1.21088	.86256	71.234
.75468	.53760	71.236
.38577	.27486	71.250
1.51040	1.07594	71.235
		Mean, 71.242±.0022
		Corrected to a vacuum, 71.230

Hence, Se=79.26.

The determinations by Jannek and Meyer [4] were made by oxidizing selenium by means of nitric acid. Elaborate precautions were taken to insure purity of materials and also of the dioxide formed. Their data with vacuum weights, are as follows:

Se.	*SeO_2.*	*Per cent Se.*
2.32307	3.26249	71.205
2.00162	2.81083	71.211
2.14178	3.00789	71.205
3.29634	4.62932	71.208
2.10447	2.95522	71.212

[1] Ber. Deutsch. chem. Ges., 34, 570. 1901.
[2] Ber. Deutsch. chem. Ges., 35, 1591. 1902.
[3] Trans. Bohemian Acad., 19 (2), No. 3. Work done under Brauner's direction.
[4] Zeitsch. anorg. Chem., 83, 51. 1913.

Se.	*SeO_2.*	*Per cent Se.*
4.82540	6.77635	71.209
5.91515	8.30670	71.210
2.43479	3.41935	71.206
2.95206	4.14583	71.205
3.27487	4.59907	71.207
		Mean, 71.208±.0018

Hence, Se= 79.142.

The data for the percentage of Se in SeO_2 now combine as follows:

Sacc	71.088 ±.0320
Ekman and Pettersson	71.191 ±.0016
Kŭzma and Křehlik	71.230 ±.0022
Jannek and Meyer	71.208 ±.0018
General mean	71.2045±.0010

Bruylants and Bytebier[1] derive their value for the atomic weight of selenium from the density of hydrogen selenide. For the weight of one liter of the gas at Louvain, at 0° and 760 mm. pressure, four globes were used and the weights were reduced to a vacuum. The weights are as follows:

1.	*2.*	*3.*	*4.*
3.67108	3.67101	3.67215	3.67120
3.67128	3.67101	3.67074	3.67243
3.67141	3.67132	3.67163	3.67106
3.67096	3.67110	3.67142	3.67216
.....	.....	3.67246	3.67240

Mean of all as one series, 3.67149±.00009.

The authors also determined the weight of a liter of oxygen under the same conditions. The weights are as follows:

1.	*2.*	*3.*	*4.*
1.42941	1.42977	1.42933	1.42942
1.42969	1.42932	1.42926	1.42980
.....	1.42921	.....	1.42966

Mean of all as one series, 1.42949±.000047.

Bruylants and Bytebier determined the compressibility of hydrogen selenide, and then computed the molecular weight of the gas by method of limiting densities. The value found was

$$H_2Se = 81.196;$$

whence Se=79.180. The probable error of the molecular weight is ±.0036, which may also be assigned to the atomic weight.

There are now nine ratios from which to compute the atomic weight of selenium:

(1) $SeO_2 : Se :: 100 : 71.2045 \pm .0010$.
(2) $BaSeO_3 : BaSO_4 :: 100 : 88.437 \pm .013$.
(3) $HgSe : Hg :: 100 : 71.7327 \pm .003$.
(4) $Se : 4Cl :: 100 : 178.696 \pm .125$.
(5) $Ag_2SeO_3 : 2Ag :: 100 : 62.9003 \pm .0013$.
(6) $Ag_2SeO_3 : 2AgCl :: 100 : 83.558 \pm .0017$.
(7) $Am_2SeBr_6 : Se :: 100 : 13.3224 \pm .0017$.
(8) $C_{12}H_{10}Se : 12CO_2 :: 100 : 226.536 \pm .0486$.
(9) Molecular weight of H_2Se, 81.196±.0036.

To reduce these ratios we have—

Ag=107.880±.00016	C=12.0025±.00019
Cl=35.4605±.00011	Ba=137.358±.0023
Br=79.9228±.00015	Hg=200.600±.0028
N=14.0081±.00008	H= 1.0078±.00001

[1] Bull. Acad. Belge, 1912, 856.

Hence,

From ratio—	
2	Se=78.585±.0388
8	78.981±.0501
3	79.048±.0092
1	79.118±.0030
9	79.180±.0036
7	79.250±.0102
5	79.259±.0078
6	79.332±.0077
4	79.376±.0555
General mean	Se=79.168±.0020

This value is near the one derived from the density of hydrogen selenide. In default of more evidence it seems to be as trustworthy as any value which might be arbitrarily chosen.

TELLURIUM.

Particular interest attaches to the atomic weight of tellurium on account of its relations to the periodic system. According to that system, tellurium should lie between antimony and iodine, having an atomic weight greater than 120 and less than 126. Theoretically, Mendeléef assigns it a value of Te = 125, but all of the best determinations lead to a mean number higher than is admissible under the currently accepted hypotheses. Whether theory or experiment is at fault remains to be discovered.

The first, and for many years the only, determinations of the constant in question were made by Berzelius.[1] By means of nitric acid he oxidized tellurium to the dioxide, and from the increase in weight deduced a value for the metal. He published only his final results, from which, if O = 100, Te = 802.121. The three separate experiments give Te = 801.74, 801.786 and 802.838, whence we can calculate the following percentages of metal in the dioxide:

80. 057
80. 036
80. 034

Mean, 80. 042±.005

Hence, Te = 128.34.

The next determinations were made by von Hauer,[2] who resorted to the analysis of the well crystallized double salt $TeBr_4.2KBr$. In this compound the bromine was estimated as silver bromide, the values assumed for Ag and Br being respectively 108.1 and 80. Recalculating, we get from von Hauer's analyses, for 100 parts of the salt, the quantities of AgBr which are put in the third column:

K_2TeBr_6.	*Per cent Br.*	*Ag Br ratio.*
2. 000	69. 946	164. 460
6. 668	69. 8443	164. 221
2. 934	69. 9113	164. 379
3. 697	70. 0163	164. 626
1. 000	69. 901	164. 355

Mean, 164. 408±.045

Hence, Te = 127.64.

Dumas,[3] by a method for which he gives absolutely no particulars, found Te = 129.

In 1879, with direct reference to Mendeléef's theory, the subject of the atomic weight of tellurium was taken up by Wills.[4] The methods of Berzelius and von Hauer were employed, with various rigid precautions in the way of testing balance and weights, and to insure purity of material. In the first series of experiments tellurium was oxidized by nitric acid to form TeO_2. The results gave figures ranging from Te = 126.64 to 129.66.

[1] Poggend. Annalen, 28, 395. 1833.
[2] Sitzungsb. Wien. Akad., 25, 142.
[3] Ann. Chim. Phys. (3), 55, 129. 1859.
[4] Journ. Chem. Soc., Oct., 1879, p. 704.

Te.	*TeO_2.*	*Per cent Te.*
2.21615	2.77612	79.828
1.45313	1.81542	80.044
2.67093	3.33838	80.007
4.77828	5.95748	80.207
2.65029	3.31331	79.989
		Mean, 80.015±.041

Hence, Te = 128.12.

In the second series tellurium was oxidized by aqua regia to TeO_2, with results varying from Te = 128.10 to 128.32:

Te.	*TeO_2.*	*Per cent Te.*
2.85011	3.56158	80.024
3.09673	3.86897	80.040
5.09365	6.36612	80.012
3.26604	4.08064	80.037
		Mean, 80.028±.004

Hence, Te = 128.22.

By von Hauer's process, the analyses of $TeBr_4.2KBr$, Wills' figures give results ranging from Te = 126.36 to 127.90. Reduced to a common standard, 100 parts of the salt yield the quantities of AgBr given in the third column:

K_2TeBr_6.	*AgBr.*	*Ratio.*
1.70673	2.80499	164.349
1.75225	2.88072	164.398
2.06938	3.40739	164.657
3.29794	5.43228	164.717
2.46545	4.05742	164.571
		Mean, 164.538±.048

Hence, Te = 127.10.

Combined with von Hauer's mean, 164.408±.045, this gives a general mean of 164.468 ±.0324.

The next determinations in order of time were those of Brauner.[1] This chemist tried various unsuccessful methods for determining the atomic weight of tellurium, among them being the synthetic preparation of silver, copper, and gold tellurides, and the basic sulphate, Te_2SO_7. None of these methods gave sufficiently concordant results, and they were therefore abandoned. The oxidation of tellurium to dioxide by means of nitric acid was also unsatisfactory, but a series of oxidations with aqua regia gave data as follows. The third column contains the percentage of tellurium in the dioxide:

Te.	*TeO_2.*	*Per cent Te.*
2.3092	2.9001	79.625
2.8153	3.5332	79.681
4.0176	5.0347	79.798
3.1613	3.9685	79.660
.8399	1.0526	79.793
		Mean, 79.711±.0239

Hence, Te = 125.72.

In a single analysis of the dioxide, by reduction with SO_2, 2.5489 grammes TeO_2 gave 2.0374 of metal. If we give this experiment the weight of one observation in the synthetic series, the percentage of tellurium found by it becomes—

79.932±.0534

Hence, Te = 127.46.

Brauner's best results were obtained from analyses of tellurium tetrabromide, prepared from pure tellurium and pure bromine, and afterwards sublimed in a vacuum. This compound was titrated with standard solutions of silver, and three series of experiments, made with

[1] Journ. Chem. Soc., 55, 382. 1889.

samples of bromide of different origin, gave results as follows. The $TeBr_4$ equivalent to 100 parts of silver appears in the third column:

First series.

$TeBr_4$.	*4Ag.*	*Ratio.*
2.14365	2.06844	103.636
1.76744	1.70531	103.643
1.47655	1.42477	103.634
1.23354	1.19019	103.642

Second series.

$TeBr_4$.	*4Ag.*	*Ratio.*
3.07912	2.97064	103.651
5.47446	5.28157	103.652
3.30927	3.19313	103.637
7.26981	7.01414	103.645
3.52077	3.39667	103.654

Third series.

$TeBr_4$.	*4Ag.*	*Ratio.*
2.35650	2.27363	103.645
1.51931	1.46564	103.662
1.43985	1.38942	103.630

Mean of all as one series, 103.644±.0018

Hence, Te = 127.56. A reduction of the weighings to a vacuum raises this by 0.07 to 127.63. Still another series of analyses, made with fractionated material, gave values for tellurium running up to as high as 137. These experiments led Brauner to believe that he had found in tellurium a higher homologue of that element, a view which he has since abandoned.[1] Brauner also made a series of analyses of tellurium dibromide, but the results were unsatisfactory.

In the series of determinations by Gooch and Howland [2] an alkaline solution of tellurium dioxide was oxidized by means of standard solutions of potassium permanganate. This was added in excess, the excess being measured, after acidification with sulphuric acid, by back titration with oxalic acid and permanganate. Two series are given, varying in detail, but for present purposes they may be treated as one. The ratio $TeO_2 : O :: 100 : x$ is given in the third column:

TeO_2 taken.	*O required.*	*Ratio.*
0.1200	0.01202	10.017
.0783	.00785	10.026
.0931	.00940	10.097
.1100	.01119	10.149
.0904	.00909	10.055
.1065	.01078	10.122
.0910	.00915	10.055
.0910	.00910	10.000
.0911	.00924	10.143
.0913	.00915	10.022
.0912	.00915	10.033
.0914	.00923	10.098

Mean, 10.068±.0100

Hence, Te = 126.92.

In Staudenmaier's [3] determinations of the atomic weight of tellurium, crystallized telluric acid, H_6TeO_6, was the starting point. By careful heating in a glass bulb this compound can be

[1] Journ. Chem. Soc., 67, 549. 1895.

[2] Amer. Journ. Sci., 58, 375. 1894. Some misprints in the original publication have been kindly corrected by Professor Gooch; hence the differences between these data and the figures formerly given.

[3] Zeitsch. anorg. Chem., 10, 189. 1895.

reduced to TeO_2, and by heating in hydrogen, to metal. In the latter case finely divided silver was added to prevent volatization of tellurium. The telluric acid was fractionally crystallized, but the different fractions gave fairly constant results. I therefore group Staudenmaier's data so as to bring them into series more suitable for the present discussion:

First.—H_6TeO_6 to TeO_2.

H_6TeO_6.	*Loss in weight.*	*Per cent TeO_2.*
1. 7218	0. 5260	69. 451
2. 8402	. 8676	69. 453
4. 0998	1. 2528	69. 442
3. 0916	. 9450	69. 433
1. 1138	. 3405	69. 429
4. 9843	1. 5236	69. 432
4. 6716	1. 4278	69. 437
		Mean, 69. 440±. 0024

Hence, Te=127.16.

Second.—H_6TeO_6 to Te.

H_6TeO_6.	*Loss in weight.*	*Per cent TeO_2.*
1. 2299	0. 5471	55. 517
1. 0175	. 4526	55. 518
2. 5946	1. 1549	55. 488
		Mean, 55. 508±. 0068

Hence, Te=127.31.

Staudenmaier also gives four reductions of TeO_2 to Te in presence of finely-divided silver. The data are as follows:

TeO_2.	*Loss in weight.*	*Per cent Te.*
0. 9171	0. 1839	79. 948
1. 9721	. 3951	79. 966
2. 4115	. 4835	79. 950
1. 0172	. 2041	79. 935
		Mean, 79. 950±. 0043

Hence, Te=127.60.

Chikashige [1] resorted to Brauner's method, giving the ratio between silver and $TeBr_4$. In all essential particulars the work resembles that of Brauner, except that the tellurium, instead of being extracted from metallic tellurides, was derived from Japanese native sulphur in which it exists as an impurity. This difference of origin in the material studied gives the chief interest to the investigation. The data are as follows:

$TeBr_4$.	*Ag.*	*Ratio.*
4. 1812	4. 0348	103. 628
4. 3059	4. 1547	103. 639
4. 5929	4. 4319	103. 633
		Mean, 103. 633±. 0023
		Brauner found, 103. 644±. 0018
		General mean, 103. 640±. 0014

From Chikashige's mean, Te=127.52.

Metzner [2] determined the atomic weight of tellurium by two methods, using tellurium which had been prepared from the hydride. First, tellurium was treated with sulphuric acid and converted into the basic sulphate, Te_2SO_7. I give his weights and also the percentage of tellurium in the compound:

Te.	*Sulphate.*	*Per cent Te.*
790. 2	1245. 0	63. 982
414. 3	647. 5	63. 985
1098. 3	1717. 0	63. 966
		Mean, 63. 978±. 0040

Hence, Te=127.94.

[1] Journ. Chem. Soc., 69, 881. 1896.

[2] Compt. Rend., 126, 1716. 1898. Metzner fails to state what his weights mean. Are they milligrammes?

Secondly, Metzner prepared tellurium dioxide by hydrolysis of the tetrachloride and reduced it to tellurium by heating in a current of carbon monoxide. The reduction was effected in presence of silver, in order to avoid volatilization. His data follow, with the usual percentage of Te in TeO_2 stated in the third column:

TeO_2.	*Loss.*	*Per cent Te.*
743.2	148.8	79.978
1106.7	221.3	80.004
988.5	197.0	80.073
1312.5	262.5	79.962
		Mean, 80.004±.0165

Hence, Te = 128.032.

The determinations by Heberlein [1] represent three distinct methods, starting with crystallized telluric acid, H_6TeO_6. First, the acid was treated with hydrochloric acid, by which chlorine was liberated. The latter was distilled off and collected in a solution of potassium iodide. Iodine was set free and determined by titration with a tenth normal thiosulphate solution. If W = the weight of telluric acid, and n the number of cubic centimeters of the thiosulphate solution, the atomic weight of tellurium is given by the subjoined formula:

$$Te = \frac{20000\,W}{n} - H_6O_6$$

The first term on the right of the equation obviously represents the molecular weight of H_6TeO_6. The figures are as follows:[2]

Weight H_6TeO_6.	*Vol. thiosulphate, cc.*	*Mol. W. H_6TeO_6.*
0.22911	20.00	229.100
.5736	50.02	229.348
.4038	35.21	229.367
.4393	38.30	229.400
.32331	28.22	229.135
		Mean, 229.270±.0425

Hence, Te = 127.223.

Secondly, Heberlein employed Staudenmaier's method of reducing H_6TeO_6 to TeO_2 by careful heating in a glass bulb:

Weight acid.	*Loss.*	*Per cent TeO_2.*
1.35236	0.41431	69.364
1.76859	.54122	69.398
		Mean, 69.381±.0115

Hence, Te = 126.72.

Finally, tellurium dioxide was reduced to tellurium by heating in a current of hydrogen in presence of silver. Heberlein's two experiments are as follows:

TeO_2.	*Loss.*	*Per cent Te.*
1.35908	0.27353	79.874
1.94038	.39050	79.875
		Mean, 79.8745±.0034

Hence, Te = 127.002. Heberlein's determinations assign low values to the atomic weight of tellurium.

Steiner's determination [3] of the atomic weight was made by combustion of phenyl telluride $(C_6H_5)_2Te$. I give his weights and also the ratio $C_{12}H_{10}Te : 12CO_2 :: 100 : x$:

Weight telluride.	*Weight CO_2.*	*Ratio.*
0.2925	0.5512	188.440
.2559	.4811	188.003
.23065	.4341	188.207
.2140	.4031	188.364
.2578	.4849	188.092
		Mean, 188.221±.0549

[1] Inaug. Diss., Basel. Printed at Strassburg, 1898.

[2] The formula given by Heberlein probably involves the old atomic weights of chlorine and iodine. With modern atomic weights the value for Te would be raised. The data as printed are, however, incomplete. A correction would be uncertain, and the probable error of the determinations is so high that the change could exert no appreciable effect upon the final combination of values.

[3] Ber. Deutsch. chem. Ges., 34, 570. 1901.

Hence, Te = 126.43, a very low value. This determination only claims a rough approximation to the truth, and is not entitled to much consideration.

Pellini,[1] in his determinations of this atomic weight, returned to the time-honored methods with the dioxide. First, carefully purified telurium was oxidized by nitric acid. Secondly, tellurum dioxide was reduced by hydrogen in presence of metallic silver. The data are as follows:

Oxidation Series.

Weight Te.	*Weight TeO_2.*	*Per cent Te.*
1. 0679	1. 3353	79. 968
1. 5469	1. 9354	79. 926
2. 2386	2. 7980	80. 007
2. 4522	3. 0665	79. 967
2. 0977	2. 6239	79. 945
2. 0442	2. 5575	79. 929
2. 0434	2. 5556	79. 957
		Mean, 79. 957±. 0071

Hence, Te = 127. 657.

Reduction Series.

Weight TeO_2.	*Loss.*	*Per cent Te.*
1. 4680	0. 2944	79. 945
1. 9968	. 3993	80. 000
1. 9575	. 3932	79. 913
		Mean, 79. 953±. 0171

Hence, Te = 127. 625.

Koethner,[2] after some preliminary, but inconclusive experiments with tellurium sulphate and telluric acid, finally resorted to analyses of the basic nitrate, Te_2HNO_7. This compound was reduced by careful heating to TeO_2. In series II, as given below, the tellurium was purified by distillation in a vacuum; in series I that precaution was not taken. Weights not reduced to a vacuum:

Series I.

Nitrate.	*TeO_2.*	*Per cent TeO_2.*
2. 9373	2. 4522	83. 485
2. 7982	2. 3361	83. 486
2. 8554	2. 3840	83. 491
		Mean, 83. 487±. 0014

Hence, Te = 127.30

Series II.

Nitrate.	*TeO_2.*	*Per cent TeO_2.*
5. 30270	4. 42824	83. 510
6. 00600	5. 01543	83. 507
5. 58039	4. 65990	83. 505
28. 66904	23. 94259	83. 513
3. 83859	3. 20560	83. 510
5. 85449	4. 88930	83. 514
25. 65029	21. 412146	83. 513
		Mean, 83. 5103±. 0009

Hence, Te = 127.57.

In 1902 Scott[3] published a preliminary note on the atomic weight of tellurium. Analyses of trimethyl tellurium iodide and bromide were made, the ratio with silver iodide being determined in the first case and the titration ratio with silver in the second. I subjoin Scott's figures, with the ratio to 100AgI and 100Ag, respectively. Vacuum weights are given:

$(CH_3)_3TeI$.	*AgI.*	*Ratio.*
1. 7461	1. 3688	127. 564
6. 6425	5. 20575	127. 570
8. 0628	6. 3181	127. 614
		Mean, 127. 583±. 0105

[1] Ber. Deutsch. chem. Ges., 34, 3807. 1901. Gazz. Chim. Ital., 32, 131. 1902. In Gazz. Chim. Ital., 33 (2), 35, Pellini discusses the possibility of an admixture in ordinary tellurium, of an element having a higher atomic weight.

[2] Liebig's Annalen, 319, 1. 1901Thesis, Halle, 1901. For a critical discussion of the subject, see Koethner, Zeitsch. anorg. Chem., 34, 402, 1903. See also Seubert, Zeitsch. anorg. Chem., 33, 247; and 35, 206.

[3] Proc. Chem. Soc. 18, 112. 1902.

Hence, Te = 127.57.

$(CH_3)_3TeBr$.	Ag.	Ratio.
2.4294	1.0373	234.204
6.8424	2.9201	234.321
		Mean, 234.263 ± .0391

Hence, Te = 127.72.

Gutbier's [1] determinations began with telluric acid, H_6TeO_6. First the acid was dehydrated by heating in a stream of dry air, and the water was collected in a calcium chloride tube and weighed:

H_6TeO_6.	H_2O.	Per cent H_2O.
0.4937	0.1162	23.537
.9910	.2335	23.652
		Mean, 23.550 ± 0083

Hence, Te = 127.45.

Secondly, telluric acid was reduced to tellurium by precipitation with hydrazin hydrate. Gutbier's data are as follows:

H_6TeO_6.	Te.	Per cent Te.
0.9380	0.5204	55.480
.4963	.2754	55.491
1.0485	.5829	55.594
.8865	.4915	55.443
.4339	.2411	55.566
.3492	.1937	55.470
		Mean, 55.507 ± .0165

Hence, Te = 127.31. This percentage, combined with that found by Staudenmaier, gives a general mean of 55.5079 ± .0067.

Finally, tellurium dioxide was reduced to tellurium by the same process:

TeO_2.	Te.	Per cent Te.
0.1662	0.13287	79.946
.3136	.2507	79.942
.2799	.2238	79.957
		Mean, 79.948 ± .0031

Hence, Te = 127.585. All of Gutbier's weights were reduced to a vacuum.

In a later memoir Gutbier [2] gives two more series of reductions of tellurium dioxide. In series I the oxide was reduced by hydrogen, and in series II by hydrazin. Vacuum weights are given:

Series I.

TeO_2	Te.	Per cent Te.
2.99688	2.39585	79.944
1.30740	1.04527	79.950
2.04325	1.63380	79.955
2.61725	2.09249	79.949
3.61725	2.89222	79.956
		Mean, 79.951 ± .0015

Hence, Te = 127.609.

Series II.

TeO_2.	Te.	Per cent Te.
1.90601	1.52390	79.952
1.03532	.82784	79.959
2.2200	1.77480	79.945
		Mean, 79.952 ± .0031

Hence, Te = 127.617.

[1] Liebig's Annalen, 320, 52. 1902.

[2] Liebig's Annalen, 342, 266. 1905.

In a more extended memoir, which includes the results of the last-mentioned investigation, Gutbier[1] gives a series of analyses of basic tellurium nitrate, like those of Koethner. His figures are as follows, not reduced to a vacuum standard:

Nitrate.	*TeO_2.*	*Per cent TeO_2.*
4. 70704	3. 92380	83. 360
6. 23210	5. 20285	83. 484
5. 65043	4. 71132	83. 379
2. 86977	2. 39211	83. 355
4. 43213	3. 69833	83. 443
9. 25691	7. 73205	83. 505
7. 09070	5. 91930	83. 481
12. 2400	10. 2216	83. 508
		Mean, 83. 439±. 0156

Hence, Te = 126.75.

Gallo's[2] investigation was an attempt to determine the electrochemical equivalent of tellurium in terms of silver. Silver and tellurium were thrown down by the same current, but in different receptacles, and so were directly compared. In the third column I give the ratio 4Ag : Te : : 100 : x :

Weight Ag.	*Weight Te.*	*Ratio.*
0. 74117	0. 218412	29. 469
1. 03801	. 304514	29. 336
. 91704	. 27256	29. 722
1. 041101	. 307117	29. 499
1. 09064	. 321952	29. 519
1. 16302	. 34582	29. 666
. 968903	. 28646	29. 565
1. 518712	. 44767	29. 477
. 906561	. 26836	29. 534
. 995511	. 29586	29. 720
. 86596	. 25656	29. 627
1. 11282	. 328318	29. 503
		Mean, 29. 553±. 0221

Hence, Te = 127.53. All of Gallo's weights are on a vacuum basis. Gallo also made a series of electrolytic analyses of tellurium dioxide, as follows. The precipitation was effected in a hydrofluoric acid solution:

Weight TeO_2.	*Weight Te.*	*Per cent Te.*
0. 4624	0. 3694	79. 888
. 7429	. 5938	79. 930
. 7995	. 6390	79. 925
. 9610	. 7664	79. 750
1. 0043	. 8025	79. 906
1. 9891	1. 5890	79. 885
		Mean, 79. 881±. 0220

Hence, Te = 127.053.

Two determinations by Lenher,[3] although not next in chronological order, may be conveniently inserted here. One was by reduction of TeO_2, the other by oxidation of Te:

TeO_2.	*Te.*	*Per cent Te.*
0. 85635	0. 6845	79. 932
. 2119	. 1694	79. 943
		Mean, 79. 938±. 0037

Hence, Te = 127.50.

Norris,[4] in the course of an investigation which proved the unity of tellurium as an element, made a series of atomic weight determinations by Koethner's method. The element itself was purified by various modes of fractionation, and different fractions were found to be identical. The basic nitrate was reduced by heating to TeO_2, which was fused before weighing, a pre-

[1] Sitzungsb. phys. med. Soz. Erlangen, 37, 270. 1906. Gutbier regards these determinations as unsatisfactory.

[2] Atti Acad. Lincei (5), 14, 23. 1905. Also Gazz. Chim. Ital., 35, 245. See also Pellini, Gazz. Chim. Ital., 34, 132, on the electrolytic determination of tellurium.

[3] Journ. Amer. Chem. Soc., 30, 741. 1908.

[4] Journ. Amer. Chem. Soc., 28, 1675. 1906

caution which eliminated the possibility of contamination by inclosed gases. The uncorrected data are as follows:

Nitrate.	*TeO_2.*	*Per cent TeO_2.*
2. 28215	1. 90578	83. 508
2. 35429	1. 96615	83. 513
1. 86853	1. 56042	83. 512
1. 77348	1. 48110	83. 514
2. 31048	1. 92938	83. 506
2. 14267	1. 78936	83. 511
2. 35523	1. 96676	83. 506
2. 18860	1. 82780	83. 515
3. 29158	2. 74881	83. 510
3. 27516	1. 89993	83. 508
2. 53164	2. 11410	83. 507
2. 01327	1. 68121	83. 506
		Mean, 83. 5097±. 0006

A vacuum correction to the weights reduces this mean by 0.0074 to 83.5023. Hence, Te=127.47.

The investigation by Baker and Bennett[1] was also intended to determine the definiteness of tellurium as an element. Different preparations from different sources were studied by several methods, and all gave sensibly the same atomic weight. The results obtained by two methods are given in detail, with vacuum weights throughout. First, tellurium dioxide was heated with sulphur in tubes of glass, the two ends of the tube being packed with silver leaf to avoid loss of tellurium. Sulphur dioxide was expelled, and from its amount, as measured by the loss in weight of the apparatus, the atomic weight of tellurium was computed. The determinations by this method may be arranged in three principal series, representing the differences in the source of the initial substance, as follows: 1. Fractional crystallization of telluric acid from barium tellurate. 2. Fractional crystallization of telluric acid produced by oxidation of the element. 3. Tellurium dioxide prepared from tellurium hydride.

Series I.

Weight TeO_2.	*Loss, SO_2.*	*Per cent SO_2.*
1. 51509	0. 60838	40. 155
1. 09875	. 44074	40. 113
1. 02150	. 40993	40. 130
. 90835	. 36472	40. 152
1. 00702	. 40451	40. 169
1. 01515	. 40733	40. 125

Series II.

Weight TeO_2.	*Loss, SO_2.*	*Per cent SO_2.*
1. 56837	0. 62938	40. 130
1. 07852	. 43257	40. 108
1. 72627	. 69246	40. 142
2. 09253	. 83927	40. 108
. 83335	. 33465	40. 157
1. 15372	. 46284	40. 117
. 68618	. 67661	40. 127
. 90835	. 36472	40. 152

Series III.

Weight TeO_2.	*Loss, SO_2.*	*Per cent SO_2.*
1. 02217	0. 41050	40. 160
. 80697	. 32392	40. 140
1. 32003	. 52992	40. 145
1. 05207	. 42221	40. 131
1. 37043	. 54969	40. 111
. 95944	. 38511	40. 139
	Mean of all as one series,	40. 136±. 0028

[1] Journ. Chem. Soc., 91, 1849. 1907.

Hence, Te = 127.62. Several other determinations concordant with these are cited, but without the detailed weighings.

Baker and Bennett also determined the atomic weight of tellurium by synthesis of the tetrabromide. Tellurium and bromine were directly combined in an atmosphere of nitrogen, and the excess of bromine was expelled by a current of nitrogen at a temperature of 50°. The determinations fall into several series, representing different samples of material, but they are given here as one series:

Weight Te.	*Weight $TeBr_4$.*	*Per cent Te.*
0.61273	2.14933	28.508
.56866	1.99354	28.525
.59884	2.09951	28.523
.57894	2.03040	28.514
.54743	1.91899	28.527
.33859	1.18732	28.517
.56866	1.99354	28.526
.47643	1.67025	28.525
.56622	1.98597	28.511
.44271	1.55205	28.524
.41671	1.46177	28.508
.50611	1.77489	28.515
.37382	1.31081	28.519
.31895	1.11868	28.512
.48931	1.71554	28.522
.47156	1.65404	28.510
.40748	1.42867	28.523
.62013	2.17449	28.518
.37382	1.31081	28.519
.50822	1.78207	28.518
.12928	.45354	28.505
.42926	1.50540	28.515
.80348	2.81715	28.511
.95309	3.34193	28.512
		Mean, 28.517 ± .0009

Hence, Te = 127.54.

Baker and Bennett furthermore report a few analyses of tellurium tetrachloride which gave values for Te ranging from 127.58 to 127.64, but without weights or details. These determinations, therefore, are unavailable for discussion here.

In the determinations by Marckwald [1] telluric acid was the starting point. This compound was reduced to TeO_2 by heating, as in several former investigations, with the following results:

Weight H_6TeO_6.	*TeO_2.*	*Per cent TeO_2.*
8.6277	5.9884	69.409
12.2680	8.5135	69.396
13.0051	9.0244	69.390
8.6415	5.9947	69.371
8.4588	5.8696	69.390
8.0113	5.5599	69.401
		Mean, 69.393 ± .0035

Hence, Te = 126.81, a figure which falls below the atomic weight of iodine. The error which suggests itself is the possible retention of water or mother liquor by the telluric acid; but Marckwald obtained an acid of constant weight after prolonged drying over phosphorus pentoxide. Still, water may have been retained as an inclosure within the particles of acid, so enveloped as to be prevented from escaping.

Lenher's investigations [2] had special reference to the homogeneity of tellurium. The tellurium was obtained from three distinct sources; first, from the telluride ores of Colorado;

[1] Ber. Deutsch. chem. Ges., 40, 4730. 1907. For a criticism of Marckwald by Baker, see Chem. News, 97, 209.

[2] Journ. Amer. Chem. Soc., 31, 20. 1909. See also Lenher's figures for TeO_2, previously cited.

second, from the residues of an electrolytic copper refinery; and third, from Bohemian material. From these the double bromide K_2TeBr_6 was prepared, and this, by heating first in chlorine and afterwards in gaseous hydrochloric acid, was converted into potassium chloride. That is, the ratio $K_2TeBr_6 : 2KCl$ was measured, all weights being reduced to a vacuum. In the following table I have treated the three series as one, for the results obtained are sensibly uniform:

	K_2TeBr_6.	*KCl.*	*Per cent KCl.*
1	2.33360	0.50779	21.7599
	1.27372	.27716	21.7599
	1.47573	.32111	21.7594
	1.65715	.36059	21.7596
	1.54006	.33513	21.7608
2	1.82810	.39778	21.7592
	1.87342	.40765	21.7595
	1.48045	.32214	21.7596
	2.24775	.48911	21.7600
3	2.37899	.51767	21.7601
	1.79926	.39146	21.7562
	.94102	.20476	21.7594
	1.55357	.33806	21.7602
	1.95038	.42440	21.7599
	1.73248	.37698	21.7596
	1.81923	.39586	21.7598
			Mean, 21.7596 ± .00017

Hence, Te = 127.56.

It has already been stated that several of the more important investigations relative to the atomic weight of tellurium, have had for their purpose the establishment of its homogeneity. Up to this point all the evidence has gone to show that it is not a mixture of two elements. Tellurium from widely different sources, as in Lenher's work, gives one and the same value for its atomic weight. Fractionations by different methods have also given constant results, and it seemed as if the question had been definitely settled. Browning and Flint,[1] however, have secured evidence upon the other side, which deserves some attention. When tellurium tetrachloride is mixed with water and hydrolyzed, a large part of it is precipitated as tellurium dioxide. A part, however, remains in solution, from which it can be thrown down by ammonia and a slight excess of acetic acid. Carefully purified tellurium was treated by the process thus briefly suggested, and converted, with all due precautions, into the basic nitrate. The portion precipitated by hydrolysis gave, on analysis of the nitrate, a mean value of Te = 126.53. From the portion afterwards thrown down the value 128.97 was obtained. Other determinations, by other methods, gave similar results. The *alpha*, or first precipitate, gave mean values, in two additional series, of 126.64 and 126.31. The *beta* portion, that not precipitated during hydrolysis of the chloride, gave Te = 128.77 and 128.81.

In 1910 a continuation of this research was published by Flint.[2] Ten fractionations of his tellurium were made, and the tenth one gave an atomic weight of 124.32, an astonishingly low figure. His first (or "alpha") portion, however, yielded figures which are more nearly normal. They are—

Nitrate.	*TeO_2.*	*Per cent TeO_2.*
4.26930	3.56471	83.496
3.66863	3.06339	83.502
3.17350	2.64983	83.499
3.43498	2.86827	83.502
5.47269	4.56963	83.499
		Mean, 83.500 ± .0008

Hence, Te = 127.45.

[1] Amer. Journ. Sci., (4) 28, 347. 1909.

[2] Amer. Journ. Sci., (4) 30, 209. 1910.

One more series of analyses of the nitrate prepared from ordinary tellurium are given by Flint in a later paper.[1] The figures are as follows:

Nitrate.	TeO_2.	*Per cent* TeO_2.
3.2059	2.6766	83.490
5.1043	4.2620	83.498
4.6762	3.9046	83.499
6.3670	5.3160	83.493
		Mean, 83.495±.0013

Hence, Te = 127.39.

The work done by Marckwald and Foizik[2] is very obscurely described. By a volumetric method TeO_2 was oxidized by potassium permanganate, but the figures given by the authors do not show directly how much oxygen was taken up. Neither do they explain how their values for the atomic weight of tellurium were calculated. Eighteen determinations are given, in mean Te = 127.610 ± .0592; a good value, but with so large a probable error that it would count for little or nothing in the final combination with other more concordant figures.

In the same memoir Foizik gives three experiments on the dehydration of telluric acid. The figures are as follows

H_6TeO_6.	TeO_2.	*Per cent* TeO_2.
9.4733	6.5762	69.418
9.3118	6.4656	69.434
8.9910	6.2415	69.420
		Mean, 69.424±.0047

Hence, Te = 127.04.

This combines with previous determinations of this ratio as follows:

Staudenmaier	69.440±.0024
Heberlein	69.381±.0115
Marckwald	69.393±.0035
Foizik	69.424±.0047
General mean	69.424±.0018

This mean is not of much significance, for Baker and Adlam[3] have shown that telluric acid always contains an excess of water, probably enclosed within the crystals. Consequently the analyses give tellurium an atomic weight much too low.

Harcourt and Baker[4] hydrolyzed tellurium tetrachloride as was done by Browning and Flint. Four fractions were then treated by the method of Baker and Bennett; that is, by conversion of the element into the tetrabromide. The results obtained, for the four distinct fractions were as follows

Te.	*Br.*	*Per cent Te in* $TeBr_4$.
0.87822	2.20103	28.521
.59706	1.49640	28.520
.69189	1.73442	28.516
.62732	1.57254	28.516
.58307	1.46162	28.516
		Mean, 28.518±.0007

Hence, Te = 127.54.

No evidence was obtained to show a separation of tellurium into fractions of different atomic weight.

In 1912 Pellini[5] published a considerable number of determinations of the atomic weight of tellurium, in order to test the claims of Browning and Flint relative to the complexity of tellurium. The tetrachloride was fractionally hydrolyzed, and the fractions were examined

[1] Journ. Amer. Chem. Soc., 34, 1325. 1912. See also, p. 1669, a critical paper by Morgan, who failed to produce fractional differences in tellurium like those of Browning and Flint.

[2] Ber. Deutsch. Chem. Ges., 43, 1710. 1910.

[3] Journ. Chem. Soc., 99, 511. 1911.

[4] Journ. Chem. Soc., 99, 1311. 1911.

[5] Atti Accad. Lincei, (5), 21, 218. 1912.

by two methods; first, by conversion of tellurium into the dioxide, and secondly, by the analysis of the nitrate. By the first method, omitting one synthesis which is evidently misprinted, and giving all the determinations as one series, Pellini obtained the following results The percentages are calculated by myself, in order to make the data conform with other series.

Te.	TeO_2.	*Per cent Te.*
1.1167	1.3965	79.964
1.6507	2.0655	79.918
1.0377	1.2975	79.977
.8755	1.09435	80.002
.5285	.6592	80.173
.4366	.5444	80.198
1.4939	1.8680	79.973
1.6037	2.0062	79.937
1.5843	1.9804	79.904
1.3866	1.7351	79.915
		Mean, 79.996±.0224

Hence, Te = 127.738.

By the nitrate method the following results were obtained:

Nitrate.	TeO_2.	*Per cent* TeO_2.
3.0255	2.5268	83.517
3.3243	2.7758	83.500
3.5758	2.9861	83.509
1.3524	1.1291	83.491
1.0218	.8534	83.519
		Mean, 83.507±.0035

Hence, Te = 127.55.

Continuing the investigation, Pellini fractionated his tellurium electrolytically, and then made two sets of determinations as in the first part of his work. The data are as follows:

Te.	TeO_2.	*Per cent Te.*
1.5529	1.9420	79.964
.9966	1.2462	79.971
.8529	1.0666	79.965
		Mean, 79.967±.0014.

Hence, Te = 127.74.

Nitrate.	TeO_2.	*Per cent* TeO_2.
1.4145	1.1814	83.521
3.9674	3.3128	83.501
2.4144	2.0164	83.516
		Main, 83.513±.0023

Hence, Te = 127.60.

Pellini's determinations give values ranging from Te = 127.32 to 128.01, but with no such large variations as were found by Browning and Flint.

The two nitrate series combine with previous determinations as follows:

Koethner, 1	83.487 ±.0014
Koethner, 2	83.510 ±.0009
Gutbier	83.439 ±.0156
Norris	83.502 ±.0006
Flint, 1	83.500 ±.0008
Flint, 2	83.495 ±.0013
Pellini, 1	83.507 ±.0035
Pellini, 2	83.513 ±.0023
General mean	83.5025±.00038

Dudley and Bowers [1] attempted to determine the atomic weight of tellurium by analyses of the basic nitrate, but obtained values which were so widely and irregularly variant that they

[1] Journ. Amer. Chem. Soc., 35, 875. 1913.

abandoned the method as untrustworthy. The salt seems to be liable to contain impurities, such as water and tellurium dioxide. The authors finally resorted to the synthesis of the tetrabromide, by the method of Baker and Bennett, and give the following series of determinations:

Te.	$TeBr_4$.	*Per cent Te.*
0.300558	1.054251	28.509
.199807	.700947	28.505
.22032	.773048	28.500
.158161	.554717	28.512
.436907	1.532360	28.512
.29811	1.045485	28.514
		Mean, 28.509±.0010

Hence Te = 127.486.

Combining this series with the previous determinations we have—

Baker and Bennett	28.517±.0009
Harcourt and Baker	28.518±.0007
Dudley and Bowers	28.509±.0010
	Mean, 28.516±.0005

Dennis and Anderson[1] attempted to divide tellurium into substances of different atomic weight, by means of the fractional distillation of hydrogen telluride, but without success. Tellurium obtained from the several fractions, when converted into dioxide, gave discordant values for the atomic weight, but the discordance was attributable to defects in the method. They were not large enough to warrant the assumption that the sought for separation had occurred. Later in their investigation they made 32 determinations of the atomic weight, by the volumetric oxidation of tellurium dioxide by potassium permanganate, and obtained values from 17 fractions, ranging between 127.36 and 127.76. The mean of all is Te = 127.49 ± .0108. Unfortunately, Dennis and Anderson do not give the actual weights, either of the tellurium dioxide or of the permanganate used to oxidize it. Their results, therefore, can not be included in the systematic discussion of the more definite ratios.

The determinations of the atomic weight of tellurium by Staehler and Tesch,[2] were made by the time-honored method of oxidizing the element to TeO_2. Their very concordant data, with vacuum weights, are as follows:

Te.	TeO_2.	*Per cent Te.*
4.46603	5.58683	79.9385
6.19861	7.75415	79.9393
6.61465	8.27460	79.9392
5.76199	7.20817	79.9368
6.03396	7.54818	79.9393
6.91214	8.64677	79.9389
6.66175	8.333511	79.9393
5.87323	7.34707	79.9398
6.18154	7.73286	79.9386
6.04458	7.56145	79.9394
6.90661	8.63959	79.9414
4.91463	6.14810	79.9374
5.41885	6.77876	79.9387
		Mean, 79.9390±.00027

Hence, Te = 127.513.

The percentage of tellurium in the dioxide is now fixed by 18 series of determinations which, ranged in the order of ascending magnitude may be combined, as usual, into a genera mean:

Brauner, oxidation	79.711 ±.0239
Heberlein	79.8745±.0034
Gallo	79.881 ±.0220
Brauner, reduction	79.932 ±.0534
Lenher	79.938 ±.0037

[1] Journ. Amer. Chem. Soc., 36, 882. 1914.

[2] Zeitsch. anorg. allgem. Chem., 98, 1. 1916.

Staehler and Tesch	79.939 ±.00027
Gutbier, 1902	79.948 ±.0031
Staudenmaier	79.950 ±.0043
Gutbier, 1905, 1	79.951 ±.0015
Gutbier, 1905, 2	79.952 ±.0031
Pellini, reduction	79.953 ±.0171
Pellini, oxidation	79.957 ±.0071
Pellini, 1912, 1	79.967 ±.0014
Pellini, 1912, 2	79.996 ±.0224
Metzner	80.004 ±.0165
Wills, 1	80.015 ±.0410
Wills, 2	80.028 ±.0040
Berzelius	80.042 ±.0050
General mean	79.941 ±.00025

In this combination the determinations by Staehler and Tesch outweigh all the others. The ratios for tellurium are now as follows:

(1) $TeO_2 : Te :: 100 : 79.941 \pm .00025$.
(2) $TeO_2 : O :: 100 : 10.068 \pm .0100$.
(3) $H_6TeO_6 : 3H_2O :: 100 : 23.550 \pm .0083$.
(4) $H_6TeO_6 : TeO_2 :: 100 : 69.434 \pm .0018$.
(5) $H_6TeO_6 : Te :: 100 : 55.5079 \pm .0067$.
(6) Molecular weight H_6TeO_6, $229.270 \pm .0425$—(Heberlein).
(7) $4Ag : Te :: 100 : 29.553 \pm .0021$.
(8) $4Ag : TeBr_4 :: 100 : 103.640 \pm .0014$.
(9) $K_2TeBr_6 : 6AgBr :: 100 : 164.468 \pm .0324$.
(10) $TeBr_4 : Te :: 100 : 28.517 \pm .0005$.
(11) $TeO_2 : SO_2 :: 100 : 40.136 \pm .0028$.
(12) $Te_2SO_7 : Te :: 100 : 63.978 \pm .0040$.
(13) $Te_2HNO_7 : TeO_2 :: 100 : 83.5025 \pm .00038$.
(14) $C_{12}H_{10}Te : 12CO_2 :: 100 : 188.221 \pm .0549$.
(15) $AgI : C_3H_9TeI :: 100 : 127.583 \pm .0105$.
(16) $Ag : C_3H_9TeBr :: 100 : 234.263 \pm .0391$.
(17) $K_2TeBr_6 : 2KCl :: 100 : 21.7596 \pm .00017$.

To reduce these ratios we have—

Ag=107.880 ±.00016	N=14.0081±.00008
Cl = 35.4605±.00011	C=12.0025±.00019
Br= 79.9228±.00015	S=32.0650±.00012
I =126.926 ±.00023	K=39.0975±.00011
H=1.0078±.00001	

Hence,

From ratio—	
14	Te=126.429±.0820
2	126.919±.1579
4	127.044±.0102
6	127.223±.0425
5	127.313±.0247
9	127.396±.1350
3	127.451±.0583
13	127.478±.0075
7	127.527±.0091
1	127.529±.0016
10	127.530±.0024
8	127.546±.0062
17	127.556±.0064
15	127.569±.0247
11	127.620±.0089
16	127.722±.0422
12	127.936±.0143
General mean	Te=127.528±.0012

The atomic weight of tellurium is evidently very close to

$$Te = 127.5,$$

which rounded-off value can be used for all practical purposes. To combine the determinations by Marckwald and Foizik, $Te = 127.610 \pm .0592$, and Dennis and Anderson, $Te = 127.49 \pm .0103$, with the others, would produce no appreciable change in the final result.

ADDENDUM.

Since this work was completed some determinations of the atomic weight of tellurium have been published by Bruylants and Michielsen,[1] who made some rather complicated analyses of the hydride TeH_2.

Their data may be abbreviated as follows:

H_2Te.	Te.	H_2O.
1.95159	1.91885	0.27096
.79827	.78501	.11078
.49887	.49072	.06945

As corrected by the authors these figures give the following values for the ratio between tellurium and oxygen.

Te.	O.	At. wt. Te.
1.92094	0.24062	127.73
.78578	.09838	127.79
.49163	.06167	127.4—Rejected.

This investigation is to be regarded as preliminary. Compare the work of Dennis and Anderson, already cited.

FLUORINE.

The atomic weight of fluorine has been determined by several distinct methods; most commonly by the conversion of fluorides into sulphates. There are, however, some exceptions, which will be considered in due time.

Excluding the early results of Davy,[2] we have to consider, first, the experiments of Berzelius, Louyet, Dumas, De Luca, and Moissan with reference to the fluorides of calcium, sodium, potassium, barium, and lead.

The ratio between calcium fluoride and sulphate has been determined by the five investigators above named, and by one general process. The fluoride is treated with strong sulphuric acid, the resulting sulphate is ignited, and the product weighed. In order to insure complete transformation special precautions are necessary, such, for instance, as repeated treatment with sulphuric acid, and so on. For details like these the original papers must be consulted.

The first experiments in chronological order are those of Berzelius,[3] who operated upon an artificial calcium fluoride. He found, in three experiments, for one part of fluoride the following of sulphate:

1.749
1.750
1.751
Mean, 1.750 ± .0004

Hence, F = 18.86.

Louyet's researches[4] were much more elaborate than the foregoing. He began with a remarkably concordant series of results upon fluorspar, in which one gram of the fluoride yielded from 1.734 to 1.737 of sulphate. At first he regarded these as accurate, but he soon found that particles of spar had been coated with sulphate, and had therefore escaped action. In the following series this source of error was guarded against.

Starting with fluorspar, Louyet found of sulphate as follows:

1.742	1.744
1.744	1.7435
1.745	1.7435

Mean, 1.7437 ± .0003

Hence, F = 18.99.

[1] Bull. Acad. Belge., 1919, Nos. 2-3, p. 119.
[2] Phil. Trans., 64. 1814.
[3] Poggend. Annalen, 8, 1. 1826.
[4] Ann. Chim. Phys. (3), 25, 300. 1849.

A second series, upon artificial fluoride, gave:

1. 743
1. 741
1. 741

Mean, 1. 7417 ± .0004

Hence, F = 19.05.

Dumas[1] published but one result for calcium fluoride. 0.495 grm. gave 0.864 grm. sulphate, the ratio being 1:1.7455. Hence, F = 18.96.

De Luca[2] worked with a very pure fluor spar, and published the following results. The ratio between $CaSO_4$ and one gramme of CaF_2 is given in the third column:

CaF_2	$CaSO_4$	Ratio
0. 9305	1. 630	1. 7518
. 836	1. 459	1. 7452
. 502	. 8755	1. 7440
. 3985	. 6945	1. 7428

Hence, F = 18.95.

If we include Dumas's single result with these, we get a mean of 1.7459 ± .0011.

Moissan[3] unfortunately gives no details nor weighings, but merely states that four experiments with calcium fluoride gave values for F ranging from 19.02 to 19.08. To S he assigned the value 32.074, and probably Ca was taken as = 40. With these data his extreme values as given may be calculated back into uniformity with the ratio as stated above, becoming—

1. 7444
1. 7410

Mean, 1. 7427

Hence, F = 19.019.

If we assign this equal weight with Berzelius' series, the data for this ratio combine thus:

Berzelius	1. 7500 ± . 0004
Louyet, first series	1. 7437 ± . 0003
Louyet, second series	1. 7417 ± . 0004
De Luca with Dumas	1. 7459 ± . 0011
Moissan	1. 7427 ± . 0004
General mean	1. 7444 ± . 00018

For the ratio between the two sodium salts we have experiments by Dumas, Louyet and Moissan. According to Louyet, one gramme of NaF gives of Na_2SO_4—

1. 686
1. 683
1. 685

Mean, 1. 6847 ± . 0006

Hence, F = 19.16.

The weighings published by Dumas are as follows:

NaF.	Na_2SO_4.	Ratio.
0. 777	1. 312	1. 689
1. 737	2. 930	1. 687

Mean, 1. 688 ± . 0007

Hence, F = 19.03.

Moissan says only that five experiments with sodium fluoride gave F = 19.04 to 19.08. This was calculated with Na = 23.05 and S = 32.074. Hence, reckoning backward, the two values give for the standard ratio—

1. 6889
1. 6873

Mean, 1. 6881

Hence, F = 19.03.

[1] Ann. Chem. Pharm., 113, 28. 1860. [2] Compt. Rend., 51, 299. 1860. [3] Compt. Rend., 111, 570. 1890.

Dumas also gives experiments upon potassium fluoride. The quantity of sulphate formed from one gramme of fluoride is given in the last column:

KF.	K_2SO_4.	*Ratio.*
1.483	2.225	1.5002
1.309	1.961	1.4981
		Mean, 1.4991±.0007

Hence, F=19.02.

The ratio between barium fluoride and barium sulphate was measured by Louyet and Moissan. According to Louyet, one gramme of BaF_2 gives of $BaSO_4$—

1.332
1.331
1.330

Mean, 1.331±.0004

Hence, F=19.01.

Moissan, in five experiments, found F=19.05 to 19.09. Assuming that he put Ba=137, and S=32.074 as before, these two extremes become—

1.3311
1.3305

Mean, 1.3308

Hence, F=19.02.

Giving this equal weight with Louyet's mean, we get the subjoined combination:

Louyet	1.331 ±.0004
Moissan	1.3308±.0004
General mean	1.3309±.00028

The experiments with lead fluoride are due to Louyet, and a new method of treatment was adopted. The salt was fused, powdered, dissolved in nitric acid, and precipitated by dilute sulphuric acid. The evaporation of the fluid and the ignition of the sulphate was then effected without transfer. Five grams of fluoride were taken in each operation, yielding of sulphate:

6.179
6.178
6.178

Mean, 6.1783±.0002

Hence, F=19.12.

In Christensen's determinations[1] we find a method adopted which is radically unlike anything in the work of his predecessors. He started out with the salt $(NH_4)_2MnF_5$. When this is added to a mixture, in solution, of potassium iodide and hydrochloric acid, iodine is set free, and may be titrated with sodium thiosulphate. One molecule of the salt (as written above) liberates one atom of iodine. In four experiments Christensen obtained the following data:

Am_2MnF_5	*I.*	*Per cent.*
3.1199	2.12748	68.191
3.9190	2.67020	68.135
3.5005	2.38429	68.113
1.2727	.86779	68.185
		Mean, 68.156±.0128

Hence, F=19.040.

Still another method for determining the atomic weight of fluorine was adopted by Julius Meyer.[2] Carefully purified calcium oxide was weighed, slaked with water, and then converted into chloride by means of hydrochloric acid. The chloride solution was then repeatedly evaporated with pure hydrofluoric acid. The calcium fluoride so produced was finally ignited to

[1] Journ. prakt. Chem. (2), 35, 541. Christensen assigns to the salt double the formula here given. [2] Zeitch. anorg. Chem., 36, 313. 1903.

constant weight. On a vacuum basis his weights were as follows. The third column gives the ratio $CaO : CaF_2 :: 100 : x$:

Weight CaO.	*Weight CaF_2.*	*Ratio.*
6. 1883	8. 6215	139. 320
4. 2736	5. 9548	139. 339
6. 2931	8. 7658	139. 292
5. 7767	8. 0485	139. 327
4. 9836	6. 9426	139. 309
		Mean, 139. 317±. 0054

Hence, F = 19.026.

In a preliminary investigation McAdam and Smith [1] attempted to determine the atomic weight of fluorine by the conversion of sodium fluoride into chloride. The conversion was effected by heating the fluoride in a current of dry, gaseous hydrochloric acid. The determinations gave the following results:

NaF.	*NaCl.*	*Ratio.*
4. 3274	6. 02075	139. 132
3. 39398	4. 72260	139. 146
		Mean, 139. 139±. 0047

Hence, F = 19.012.

In the section of this recalculation upon silicon the determinations by Germann and Booth of the density of silicon tetrafluoride are discussed.[2] From their figures the molecular weight of the gas becomes $SiF_4 = 104.47 \pm .0132$. Hence, if $Si = 28.255 \pm .0025$, $F = 19.054 \pm .0034$. This value is of slight importance.

In their work on the atomic weight of boron, which has already been fully discussed,[3] Smith and Van Haagen give data from which they compute the atomic weight of fluorine. These data furnish determinations of two ratios, as follows:

Ratio $Na_2B_4O_7 : 2NaF :: 100 : x$.

$Na_2B_4O_7$.	*NaF.*	*Ratio.*
0. 69695	0. 29042	41. 670
1. 99197	. 83003	41. 669
1. 60201	. 66757	41. 671
2. 64768	1. 10329	41. 670
		Mean, 41. 670±. 0003

Ratio $2NaF : Na_2SO_4 :: 100 : x$.

NaF.	*Na_2SO_4.*	*Ratio.*
0. 29042	0. 49113	1. 69110
. 66757	1. 12889	1. 69101
1. 10329	1. 86597	1. 69132
		Mean, 1. 69114±. 00006

Hence, F = 19.002.

This ratio combines with previous determinations of it as follows:

Louyet	1. 6847 ±. 0006
Dumas	1. 688 ±. 0007
Moissan	1. 6881 ±. 0007
Smith and Van Haagen	1. 69114±. 00006
General mean	1. 69112±. 000059

In this combination Moissan's figure is assigned equal weight with that of Dumas. The ratios from which to compute the atomic weight of fluorine are now—

(1) $CaO : CaF_2 :: 100 : 139.317 \pm .0054$.
(2) $CaF_2 : CaSO_4 :: 1.0 : 1.7444 \pm .00018$.
(3) $2NaF : Na_2SO_4 :: 1.0 : 1.69112 \pm .000059$.

[1] Journ. Amer. Chem. Soc., 34, 592. 1912. [2] See *ante*, p. —. [3] See *ante*, pp. —.

(4) $2KF : K_2SO_4 :: 1.0 : 1.4991 \pm .0007$.
(5) $BaF_2 : BaSO_4 :: 1.0 : 1.3309 \pm .00028$.
(6) $PbF_2 : PbSO_4 :: 5.0 : 6.1783 \pm .0002$.
(7) $Am_2MnF_5 : I :: 100 : 68.156 \pm .0128$.
(8) $NaF : NaCl :: 100 : 139.139 \pm .0047$.
(9) $Na_2B_4O_7 : 2NaF :: 100 : 41.670 \pm .0003$.
(10) Mol. weight of SiF_4, $104.47 \pm .0132$.

To reduce these ratios we have—

Ca= 40.0902±.00023	S =32.0650±.00012
Ba=137.358 ±.0023	I =126.926±.00023
Pb=207.102 ±.00062	Cl=35.4605±.00011
Mn= 54.949 ±.00045	N=14.0081±.00008
Na= 23.0029±.00012	B=10.912 ±.0007
K = 39.0975±.00011	Si=28.255 ±.0025

H=1.0078±.00001

Hence,

From ratio—	
2	F=18.931±.0040
3	19.002±.0015
8	19.012±.0014
9	19.012±.0007
5	19.015±.0185
4	19.024±.0271
1	19.026±.0038
7	19.040±.0070
10	19.054±.0034
6	19.123±.0070
General mean	F=19.011±.00055

In this combination the determinations by Smith and Van Haagen outweigh all the others. Their determinations alone, taken in connection with their work on boron, make F=19.005. For practical purposes the rounded-off value 19 falls within the limits of uncertainty.

ADDENDUM.

The determination of the atomic weight of fluorine by Moles and Batuecas[1] appeared too late for the systematic discussion of their data. Methyl fluoride, CH_3F, was taken as a favorable substance to investigate. Twenty-three determinations were made of the weight of a normal liter of the gas, giving a corrected average of 1.54542 grammes. From this, the molecular weight 34.024 is deduced, and F=18.996, or rounded off, 19.0.

MANGANESE.

The earliest experiments of Berzelius[2] and of Arfvedson[3] gave values for Mn ranging between 56 and 57, and therefore need no further consideration here. The first determinations to be noticed are those of Turner[4] and a later measurement by Berzelius,[5] who both determined gravimetrically the ratio between the chlorides of manganese and silver. The manganese chloride was fused in a current of dry hydrochloric acid and afterwards precipitated with a silver solution. I give the $MnCl_2$ equivalent to 100 parts of AgCl in the third column:

4.20775 grm. $MnCl_2$= 9.575 grm. AgCl.	43.945	Berzelius.
3.063 " = 9.96912 "	43.950	
12.47 grains $MnCl_2$=28.42 grains AgCl.	43.878	—Turner.
	Mean, 43.924±0.015	

Hence, Mn=55.07, Berzelius; or 54.87, Turner.

[1] Journ. Chim. Phys., 17, 538. 1919.
[2] Poggend. Annalen, 8, 185. 1826.
[3] Berz. Jahresbericht, 9, 136. 1829.
[4] Trans. Roy. Soc. Edinb., 11, 143. 1831.
[5] Lehrbuch, 5 Aufl., 3, 1224.

Many years later Dumas[1] also made the chloride of manganese the starting point of some atomic weight determinations. The salt was fused in a current of hydrochloric acid and afterwards titrated with a standard solution of silver in the usual way. One hundred parts of Ag are equivalent to the quantities of $MnCl_2$ given in the third column:

$MnCl_2$	*Ag.*	*Ratio.*
3.3672	5.774	58.317
3.0872	5.293	58.326
2.9671	5.0875	58.321
1.1244	1.928	58.320
1.3134	2.251	58.321
		Mean, 58.321±.001

Hence, Mn=54.912.

An entirely different method of investigation was followed by von Hauer,[2] who, as in the case of cadmium, ignited the sulphate in a stream of sulphuretted hydrogen and determined the quantity of sulphide thus formed. I subjoin his weighings and also the percentage of MnS formed from $MnSO_4$ as calculated from them:

$MnSO_4$.	*MnS.*	*Per cent.*
4.0626	2.3425	57.660
4.9367	2.8442	57.613
5.2372	3.0192	57.649
7.0047	4.0347	57.600
4.9175	2.8297	57.543
4.8546	2.7955	57.585
4.9978	2.8799	57.625
4.6737	2.6934	57.629
4.7240	2.7197	57.572
		Mean, 57.608±.008

Hence, Mn=54.907.

This method of von Hauer, which seemed to give good results with cadmium, is, according to Schneider,[3] inapplicable to manganese, for the reason that the sulphide of the latter metal is liable to be contaminated with traces of oxysulphide. Such an impurity would make the atomic weight too high. The results of two different processes, one carried out by himself and the other in his laboratory by Rawack, are given by Schneider in this paper.

Rawack reduced manganoso-manganic oxide to manganous oxide by ignition in a stream of hydrogen and weighed the water thus formed. From his weighings I get the values in the third column, which represent the Mn_3O_4 equivalent to one gramme of water:

Mn_3O_4	*H_2O.*	*Ratio.*
4.149	0.330	12.5727
4.649	.370	12.5643
6.8865	.5485	12.5552
7.356	.5855	12.5636
8.9445	.7135	12.5361
11.584	.9225	12.5572
		Mean, 12.5582±.0034

Hence, Mn=54.08.

Here the most obvious source of error lies in the possible loss of water. Such a loss, however, would increase the apparent atomic weight of manganese, but we see that the value found is much lower than that obtained either by Dumas or von Hauer.

Schneider himself effected the combustion of manganous oxalate with oxide of copper. The salt was not absolutely dry, so that it was necessary to collect both water and carbon dioxide. Then, upon deducting the weight of water from that of the original material, the weight of anhydrous oxalate was easily ascertained. Subtracting from this the CO_2 we get

[1] Ann. Chem. Pharm., 113, 25. 1860. [2] Journ. prakt. Chem., 72, 360. 1857. [3] Poggend. Annalen, 107, 605.

the weight of Mn. If we put $CO_2 = 100$, the quantities of manganese equivalent to it will be found in the last column:

Oxalate.	*H_2O.*	*CO_2.*	*Ratio.*
1. 5075	0. 306	0. 7445	61. 3835
2. 253	. 4555	1. 1135	61. 4291
3. 1935	. 652	1. 5745	61. 4163
5. 073	1. 028	2. 507	61. 3482
			Mean, 61. 3943 ± . 0122

Hence, Mn = 54.03.

Up to this point the data give two distinct values for Mn—one near 54, the other approximately 55—and with no sure guide to preference between them. The higher value, however, has been confirmed by later testimony.

In 1883 Dewar and Scott [1] published the results of their work upon silver permanganate. This salt is easily obtained pure by recrystallization and has the decided advantage of not being hygroscopic. Two sets of experiments were made. First, the silver permanganate was heated to redness in a glass bulb, first in air, then in hydrogen. Before weighing the latter gas was replaced by nitrogen. The data are as follows:

$AgMnO_4$.	*$Ag + MnO$.*	*Per cent $Ag + MnO$.*
5. 8696	4. 63212	78. 917
5. 4988	4. 33591	78. 852
7. 6735	6. 05395	78. 894
13. 10147	10. 31815	78. 756
12. 5799	9. 91065	78. 782
	9. 91435	78. 811
		Mean, 78. 835 ± . 0174

Hence, Kn = 55.009.

The duplication of the last weighing is not explained.

In the second series the permanganate was dissolved in dilute nitric acid, reduced by sulphur dioxide, potassium nitrite, or sodium formate, and titrated with potassium bromide. The $AgMnO_4$ equivalent to 100 KBr appears in the third column:

$AgMnO_4$.	*KBr.*	*Ratio.*
6. 5289	3. 42385	190. 686
7. 5378	3. 9553	190. 575
6. 1008	3. 20166	190. 559
5. 74647	3. 00677	191. 117
6. 16593	3. 23602	190. 540
5. 11329	2. 6828	190. 596
5. 07438	2. 66204	190. 624
13. 4484	7. 05603	190. 604
12. 5799	6. 60065	190. 588
12. 27025	6. 43808	190. 584
		Mean, 190. 647 ± . 0361

Vacuum weights are given throughout. To the first series of experiments the authors attach little importance, and numbers 1 and 4 of the second series they also regard as questionable. These experiments involved the use of sulphur dioxide as the reducing agent, and were attended by the formation of an insoluble residue, apparently of a sulphide. Excluding them, the remaining eight experiments of the second series give in mean—

$$KBr : AgMnO_4 :: 100 : 190.584 \pm .0062, \text{ and } Mn = 54.95$$

which will be used for the present calculation. Dewar and Scott also made determinations with manganese chloride and bromide. With the first salt they found Mn = 54.91, and with the second, Mn = 54.97; but they give no details.

[1] Proc. Roy. Soc., 35, 44. 1883.

Marignac's work upon the atomic weight of manganese also appeared in 1883.[1] He prepared the oxide, MnO, by ignition of the oxalate and subsequent reduction of the resulting Mn_3O_4 in hydrogen. The oxide, with various precautions, was then converted into sulphate. The percentage of MnO in $MnSO_4$ is appended:

MnO.	*$MnSO_4$.*	*Per cent.*
2.6587	5.6530	47.032
2.5185	5.3600	46.987
2.5992	5.5295	47.006
2.8883	6.1450	47.002
		Mean, 47.007±.0025

Hence, Mn=55.023.

J. M. Weeren, in 1890,[2] published determinations made by two methods, the one Marignac's, the other von Hauer's. From manganese sulphate he threw down the hydrated peroxide electrically, and the latter compound was then reduced in hydrogen which had been proved to be free from oxygen. The resulting monoxide was cooled in a stream of purified nitrogen. After the oxide had been treated with sulphuric acid, converted into sulphate, and weighed, a few drops of sulphuric acid and a little sulphurous acid were added to it, after which it was reheated and weighed again. This process was repeated until four successive weighings absolutely agreed. The results of this set of experiments were as follows, reduced to a vacuum:

MnO.	*$MnSO_4$.*	*Per cent.*
15.2349	32.4142	47.005
13.9686	29.7186	47.004
13.7471	29.2493	47.000
15.5222	33.0246	47.001
14.9824	31.8755	47.002
14.6784	31.2304	47.000
		Mean, 47.002±.0006

Hence, Mn=55.007.

Marignac's mean, combined with this, hardly affects either the percentage itself or its probable error. Fortunately, both Marignac and Weeren are completely in agreement as to the ratio, and either set of measurements would be valid without the other. In order, therefore, to give Marignac's work some proper recognition, we can assume a general mean of 47.004± .0006, without danger of serious error.

The manganese sulphate produced in the foregoing series of experiments was used, with many precautions, for the next series carried out by von Hauer's method. It was transferred to a porcelain boat, dried at 260° to avoid errors due to retention of water taken up in the process of transfer, and then heated to constant weight in a stream of hydrogen sulphide. Before weighing, the sulphide was heated to redness in hydrogen and cooled in the same gas. The results, with vacuum weights, were as follows:

$MnSO_4$.	*MnS.*	*Per cent.*
16.0029	9.2228	57.632
16.3191	9.4048	57.631
15.9307	9.1817	57.634
15.8441	9.1315	57.634
16.2783	9.3819	57.635
17.0874	9.8477	57.633
		Mean, 57.633±.0004
		von Hauer found, 57.608±.0080

Hence, the general mean is identical with Weeren's to the third decimal place, which is unaffected by combination with von Hauer's data.

From Weeren's figures alone Mn=54.994.

[1] Arch. Sci. Phys. Nat. (3), 10, 21. 1883.

[2] Atom-Gewichtsbestimmung des Mangans. Inaugural Dissertation, Halle, 1890.

The determinations by Baxter and Hines [1] were based upon analyses of manganese bromide and chloride, both fused in order to eliminate moisture. The usual Harvard methods were employed, giving two ratios for each salt. With vacuum weights the data obtained were as follows, first with the bromide:

$MnBr_2$.	$AgBr$.	Ag.	Ag ratio.	AgBr ratio.
5.58416	9.76561	.....	.....	57.181
5.63432	9.85345	.....	.....	57.181
6.53738	11.43300	6.56765	99.539	57.180
4.81005	8.41206	4.83238	99.538	57.180
4.88097	8.53642	4.90354	99.540	57.178
5.63219	9.85008	5.65813	99.542	57.179
6.52626	11.41293	.....	.....	57.183
5.79924	10.14206	5.82600	99.541	57.180
3.59809	6.29271	3.61478	99.538	57.179
5.16334	9.02959	5.18711	99.542	57.182
3.92226	6.85968	3.94042	99.539	57.178
4.49158	7.85571	4.51250	99.536	57.176
3.60071	6.29740	3.61736	99.540	57.178
4.77392	8.34915	4.79620	99.535	57.179
3.57660	6.25569	3.59319	99.538	57.174
5.69972	9.96840	5.72641	99.534	57.178
			Mean, 99.539±.0005	57.179±.0004

From the Ag ratio, Mn = 54.921.
From the AgBr ratio, Mn = 54.922.
And Ag : Br :: 100 : 74.083.
Secondly, for the chloride series:

$MnCl_2$.	$AgCl$.	Ag.	Ag ratio.	AgCl ratio.
4.62970	10.54641	7.93740	58.328	43.898
3.52899	8.03868	6.05041	58.326	43.900
3.30881	7.53731	5.67279	58.328	43.899
3.56843	8.12932	6.11818	58.325	43.896
3.45083	7.86129	5.91637	58.327	43.896
4.47948	10.20372	7.67995	58.327	43.900
3.92089	8.93140	6.72227	58.327	43.900
			Mean, 58.327±.0003	43.898±.0005

From the Ag ratio, Mn = 54.925.
From the AgCl ratio, Mn = 54.926.
And Ag : Cl :: 100 : 32.869.
The chloride ratios, as determined by different chemists, combine thus:

Ag ratio.

Dumas	58.321 ±.0010
Baxter and Hines	58.327 ±.0003
General mean	58.3265±.0003

Ag Cl ratio.

Berzelius with Turner	43.924 ±.0150
Baxter and Hines	43.898 ±.0005
General mean	43.898 ±.0005

In this instance the early work does not even effect the fourth decimal place.
We have now to consider the following ratios for manganese:

(1) $2Ag : MnCl_2 :: 100 : 58.3265 \pm .0003$.
(2) $2AgCl : MnCl_2 :: 100 : 43.898 \pm .0005$.
(3) $2Ag : MnBr_2 :: 100 : 99.539 \pm .0005$.
(4) $2AgBr : MnBr_2 :: 100 : 57.179 \pm .0004$.

[1] Journ. Amer. Chem. Soc., 28, 1560. 1906.

(5) $H_2O : Mn_3O_4 :: 100 : 1255.82 \pm .3400$.
(6) $2CO_2 : Mn :: 100 : 61.3943 \pm .0122$.
(7) $AgMnO_4 : Ag + MnO :: 100 : 78.835 \pm .0174$.
(8) $KBr : AgMnO_4 :: 100 : 190.584 \pm .0062$.
(9) $MnSO_4 : MnO :: 100 : 47.004 \pm .0006$.
(10) $MnSO_4 : MnS :: 100 : 57.633 \pm .0004$.

The antecedent atomic weights are—

AgClBr	Ag=107.880 ±.00016	S=32.0650±.00012
	Cl= 35.4605±.00011	K=39.0975±.00011
	Br= 79.9228±.00015	C=12.0025±.00019
		H=1.0078±.00001

Hence,

From ratio—	
6	Mn=54.030±.0108
5	54.081±.0610
3	54.921±.0012
4	54.922±.0016
1	54.924±.00077
2	54.926±.0014
8	54.954±.0074
10	54.996±.0010
7	55.009±.1522
9	55.013±.0012
General mean	54.949±.00045

In this combination the best work is evidently that of Baxter and Hines, as shown by the concordant values derived from ratios 1 to 4. But Weeren's work also appears to be excellent, and ought not to be ignored. The general mean takes all the trustworthy determinations into account, and seems to be preferable to any selection among them.

IRON.

The atomic weight of iron has been mainly determined from the composition of ferric oxide, ferrous bromide, and the two chlorides.

Most of the earlier data relative to the percentage of metal and oxygen in ferric oxide we may reject at once, as set aside by later investigations. Among this no longer valuable material there is a series of experiments by Berzelius, another by Döbereiner, and a third by Capitaine.[1] The first work deserving of present consideration is that of Wackenroder,[2] who reduced the oxide in hydrogen at a moderate red heat. The following percentages of iron were thus found:

69.62	69.98
69.954	69.99
69.98	70.04

Mean, 69.927±.0905

If we reject the first of these figures the mean becomes 69.988±.0099, which is more trustworthy. Hence, Fe=55.97.

In 1844 Berzelius[3] published two determinations of the ratio in question. He oxidized iron by means of nitric acid, and weighed the oxide thus formed. He thus found that when O=100 Fe=350.27 and 350.369.

Hence the following percentages of Fe in Fe_2O_3:

70.018
70.022

Mean, 70.020±.0013

[1] For details concerning these earlier reseraches, see Oudeman's monograph, pp. 140, 141.
[2] Arch. Pharm., 35, 279, and 36, 22. 1843.
[3] Berz. Jahresb., 25, 43. Ann. Chem. Pharm., 30, 432.

Hence, Fe = 56.05. The "probable error" assigned to this pair of measurements greatly overvalues them. It is better, therefore, to give the mean equal weight with Wackenroder's, making it $70.020 \pm .0099$.

About the same time Svanberg and Norlin [1] published two elaborate series of experiments; one relating to the synthesis of ferric oxide, the other to its reduction. In the first set pure piano-forte wire was oxidized by nitric acid, and the amount of oxide thus formed was determined. The results were as follows:

Fe.	Fe_2O_3.	*Per cent Fe.*
1. 5257	2. 1803	69. 977
2. 4051	3. 4390	69. 936
2. 3212	3. 3194	69. 928
2. 32175	3. 3183	69. 968
2. 2772	3. 2550	69. 960
2. 4782	3. 5418	69. 970
2. 3582	3. 3720	69. 935
		Mean, 69. 9534 ± .0050

Hence, Fe = 55.875.

In the second series ferric oxide was reduced by ignition in a current of hydrogen, yielding the subjoined percentages of metal:

Fe_2O_3.	*Fe.*	*Per ct.*
2. 98353	2. 08915	70. 025
2. 41515	1. 6910	70. 015
2. 99175	2. 09455	70. 014
3. 5783	2. 505925	70. 030
4. 1922	2. 9375	70. 072
3. 1015	2. 17275	70. 056
2. 6886	1. 88305	70. 036
		Mean, 70.0354 ± .0055

Hence, Fe = 56.093.

It is evident that one or both of these series must be vitiated by constant errors, and that these probably arise from impurities in the materials employed. Impurities in the wire taken for the oxidation series could hardly have been altogether avoided.

In 1844 there was also published an important paper by Erdmann and Marchand.[2] These chemists prepared ferric oxide by the ignition of pure ferrous oxalate, and submitted it to reduction in a stream of hydrogen. Two sets of results were obtained with two different samples of ferrous oxalate, prepared by two different methods. For present purposes, however, it is not necessary to discuss these sets separately. The percentages of iron in Fe_2O_3 are as follows:

70. 013	
69. 962	
69. 979	A
70. 030	
69, 977	
70. 044	
70. 015	B
70. 055	
Mean, 70. 0094 ± .0080	

Hence, Fe = 56.025.

In 1850 Maumené's [3] determinations appeared. He dissolved pure iron wire in aqua regia, precipitated with ammonia, filtered off the precipitate, washed thoroughly, ignited and weighed after the usual methods of quantitative analysis. The percentages of Fe in Fe_2O_3 are given in the third column:

Fe.	Fe_2O_3.	*Per cent.*
1. 482	2. 117	70. 005
1. 452	2. 074	70. 010
1. 3585	1. 941	69. 990

[1] Berz. Jahresb., 25, 42. [2] Journ. prakt. Chem., 33, 1. [3] Compt. Rend., Oct. 17, 1850.

Fe.	Fe_2O_3.	*Per cent.*
1.420	2.0285	70.002
1.492	2.1315	69.998
1.554	2.220	70.000
		Mean, 70.0008±.0019

Hence, Fe=56.003.

The two determinations by Rivot [1] are quite unimportant. This chemist reduced ferric oxide in hydrogen, and obtained the subjoined percentages of iron:

69.31
69.35
Mean, 69.33±0130

Hence, Fe=54.25.

Richards and Baxter [2] also reduced ferric oxide by hydrogen. Iron was purified electrolytically and then converted into oxide by two processes. First, by solution, precipitation as hydroxide, and ignition of the latter compound. With the oxide thus prepared, the two subjoined reductions were made:

Fe_2O_3.	*Fe.*	*Per cent Fe.*
3.17485	2.22096	69.954
3.61235	2.52750	69.968
		Mean, 69.961±.0047

Hence, Fe=55.900.

Secondly, iron was converted into nitrate, and that into oxide by calcination. The oxide was free from occluded gases. The data, with vacuum weights for both series, are as follows:

Fe_2O_3.	*Fe.*	*Per cent Fe.*
3.97557	2.78115	69.956
4.89655	3.42558	69.959
4.35955	3.04990	69.959
7.14115	4.99533	69.951
6.42021	4.49130	69.956
		Mean, 69.9562±.0010

Hence Fe=55.883.

Still more recently, Baxter and Hoover [3] have published two more series of reductions of ferric oxide, one of material prepared from ordinary iron, the other of material from meteoric iron. The two samples of iron were thus proved to be identical in character. The data, with vacuum weights, are as follows:

1. Ordinary iron.

Fe_2O_3.	*Fe.*	*Per cent Fe.*
4.86111	3.39995	69.9418
7.59712	5.31364	69.9428
6.50945	4.55298	69.9442
8.00040	5.59576	69.9435
7.27260	5.08661	69.9421
7.69441	5.38155	69.9410
7.33754	5.13213	69.9435
		Mean, 69.9427±.0003

Hence, Fe=55.847.

2. Meteoric iron.

Fe_2O_3.	*Fe.*	*Per cent Fe.*
4.46431	3.12240	69.9414
4.85179	3.39351	69.9435
5.21397	3.64674	69.9417
5.99087	4.19030	69.9448
6.70197	4.68752	69.9425
		Mean, 69.9428±.0004

Hence, Fe=55.848.

[1] Ann. Chem. Pharm., 78, 214. 1851.
[2] Proc. Amer. Acad., 35, 253. Zeitsch. anorg. Chem., 23, 245. 1900.
[3] Journ. Amer. Chem. Soc., 34, 1657. 1912.

The eleven series of figures for this ratio combine thus:

Wackenroder	69.988 ±.0099
Berzelius	70.020 ±.0099
Erdmann and Marchand	70.0094 ±.0080
Svanberg and Norlin, oxidation	69.9534 ±.0050
Svanberg and Norlin, reduction	70.0354 ±.0055
Maumené	70.0008 ±.0019
Rivot	69.33 ±.0013
Richards and Baxter, 1	69.961 ±.0047
Richards and Baxter, 2	69.9562 ±.0010
Baxter and Hoover, 1	69.9427 ±.0003
Baxter and Hoover, 2	69.9428 ±.0004
General mean	69.9451 ±.00023

Dumas'[1] results, obtained from the chlorides of iron, are of so little weight that they might safely be omitted from our present discussion. For the sake of completeness, however, they must be included.

Pure ferrous chloride, ignited in a stream of hydrochloric acid gas, was dissolved in water and titrated with a silver solution in the usual way. One hundred parts of silver are equivalent to the amounts of $FeCl_2$ given in the third column:

$FeCl_2$.	*Ag.*	*Ratio.*
3.677	6.238	58.945
3.924	6.675	58.787
		Mean, 58.866±.053

Ferric chloride, titrated in the same way, gave these results:

$FeCl_3$.	*Ag.*	*Ratio.*
1.179	2.3475	50.224
1.242	2.471	50.263
		Mean, 50.2435±.0132

These give us two additional values for Fe, as follows:

From $FeCl_2$	Fe=56.089
From $FeCl_3$	Fe=56.226

A series of determinations of the equivalent of iron, made by students by measuring the hydrogen evolved when the metal is dissolved in an acid, was published by Torrey in 1888.[2] The data have, of course, slight value, but may be considered as being in some measure confirmatory. They are as follows:

56.40	56.06
55.60	56.22
55.38	55.80
55.56	55.78
55.48	55.60
55.50	55.70
55.86	55.94

Mean, 55.777±.0532

These values undoubtedly depend on Regnault's value for the weight of hydrogen. Correcting by the later value, as found in the chapter of this work relating to the density ratio H : O, the mean becomes Fe=55.608±.0532. With O=16, Fe=56.042. The probable error in the weight of the hydrogen is ignored as having no practical significance.

A few determinations of the atomic weight of iron by Winkler[3] need to be mentioned, not as directly significant, but as relating to the validity of a method which he applied to nickel and cobalt. Iron, not absolutely pure, was dissolved in a solution of iodine and potassium iodide. The quantity of iodine was known, and after the reaction ended the amount unconsumed was measured by titration with thiosulphate solution. A ratio between iodine and iron was thus

[1] Ann. Chem. Pharm., 113, 26. 1860. [2] Amer. Chem. Journ., 10, 74. [3] Zeitschr. anorg. Chem., 8, 291. 1895.

determined, which can be expressed as $I_2 : Fe : : 100 : x$. Two series are given, one with iron cleaned by scrubbing, the other with iron which had been heated in hydrogen. The weights of iron given below are corrected for known impurities:

Series I.

Fe.	*I.*	*Ratio.*
0.5726	2.585609	22.146
.5778	2.608375	22.152
.5721	2.582935	22.149
		Mean, 22.149±.0012

Hence, Fe=56.226.

Series II.

Fe.	*I.*	*Ratio.*
0.8252	3.727316	22.139
.8430	3.809144	22.131
.8349	3.771613	22.137
		Mean, 22.136±.0017

Hence, Fe=56.193. The weighted mean of both series is 22.145±.0010, which gives Fe=56.216. This value is high, and so are the values found for cobalt and nickel by the same method. The process is probably affected by serious constant errors, and the results obtained by it are not good. For comparative purposes, however, the iodine ratio is included in the final tabulation of ratios:

The best determinations of the atomic weight of iron appear to be those by Baxter and his colleagues, and are based upon analyses of ferrous bromide. Of these the earlier are by Baxter alone,[1] who made two sets of analyses, fixing the two usual ratios, by the established Harvard methods. His figures, with all corrections and vacuum weights, follow:

$FeBr_2$.	*AgBr.*	*Ag.*	*Ag ratio.*	*AgBr ratio.*
3.55929	6.19873	.....	.....	57.420
3.07448	5.35450	.....	.....	57.419
2.96102	5.15696	2.96234	99.956	57.418
4.00791	6.97983	4.00937	99.964	57.421
			Mean, 99.960±.0027	57.4195±.00044

From the Ag ratio, Fe=55.828.
From the AgBr ratio, Fe=55.825.
And Ag:Br::100:74.087.

The analyses of ferrous bromide by Baxter, Thorvaldson and Cobb[2] fall into two series, one preliminary, the other final. The data, with vacuum weights, are as follows:

Preliminary series.

$FeBr_2$	*Ag.*	*AgBr.*	*Ag ratio*	*AgBr ratio.*
3.45339	3.45481	6.01358	99.9589	57.4265
3.04933	3.05055	5.31029	99.9600	57.4228
2.9007	2.9019	.....	99.9586	.....
3.0873	3.0885	.....	99.9611	.....
3.50278	3.50426	6.10033	99.9577	57.4195
4.05239	4.05404	7.05752	99.9593	57.4195
4.08516	4.08683	.....	99.9593	.....
			Mean, 99.9593±.00027	57.4221±.00114

From the Ag ratio Fe=55.826.
From the AgBr ratio Fe=55.835.
And Ag:Br::100:74.077.

[1] Proc. Amer. Acad., 39, 245. 1903.

[2] Journ. Amer. Chem. Soc., 33 319. 1911.

Final series.

$FeBr_2$.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
5.03555	5.03774	8.76950	99.9565	57.4212
6.06309	6.06557	10.55889	99.9592	57.4216
5.59258	5.59482	9.73974	99.9599	57.4202
5.89767	5.90014	10.27057	99.9581	57.4230
4.48546	4.48742	.....	99.9563	.....
5.41562	5.41799	9.43171	99.9563	57.4193
6.50002	6.50277	11.31958	99.9577	57.4227
3.56564	3.56719	6.20987	99.9565	57.4189
5.32434	5.32642	9.27237	99.9609	57.4216
6.38845	5.39094	11.12536	99.9610	57.4224
6.37952	6.38213	10.10971	99.9591	57.4229
8.51818	.....	14.83468	.....	57.4207
			Mean, 99.9583±.00057	57.4213±.00029

From the Ag ratio Fe = 55.824.
From the AgBr ratio Fe = 55.832.
And Ag:Br::100:74.079.

There is also another series of analyses by Baxter and Thorvaldson[1] of ferrous bromide prepared from meteoric iron. Their data are as follows:

$FeBr_2$.	Ag.	AgBr.	Ag ratio.	AgBr ratio.
3.95460	3.95631	6.88720	99.9568	57.4196
4.66954	4.67177	8.13282	99.9523	57.4160
4.75335	4.75550	8.27855	99.9548	57.4177
6.95582	6.95854	12.11329	99.9609	57.4230
3.20762	3.20904	5.58632	99.9557	57.4192
			Mean, 99.9561±.00093	57.4191±.00078

From the Ag ratio Fe = 55.819.
From the AgBr ratio Fe = 55.823.
And Ag:Br::100:74.081.

These series relative to ferrous bromide now combine thus—

	Ag ratio.	AgBr ratio.
Baxter	99.960 ±.0027	57.4195±.00044
Baxter, Thorvaldson, and Cobb, 1	99.9593±.00027	57.4221±.00114
Baxter, Thorvaldson, and Cobb, 2	99.9583±.00051	57.4213±.00029
Baxter and Thorvaldson	99.9561±.00078	57.4191±.00078
General mean	99.9585±.00024	57.4203±.00023

The ratios relative to the atomic weight of iron are now as follows:

(1) $Fe_2O_3 : 2Fe : 100 : 69.9451 \pm .00023$.
(2) $2Ag : FeBr_2 : 100 : 99.9585 \pm .00024$.
(3) $2AgBr : FeBr_2 : 100 : 57.4203 \pm .00023$.
(4) $2Ag : FeCl_2 : 100 : 58.866 \pm .0530$.
(5) $3Ag : FeCl_3 : 100 : 50.2435 \pm .0132$.
(6) $I_2 : Fe : 100 : 22.145 \pm .0010$.
(7) $H : Fe : 1 : 55.608 \pm .0532$.

The antecedent values are—

Ag = 107.880 ±.00016 Br = 79.9228±.00015
Cl = 35.4605±.00011 I = 126.926 ±.00023
H = 1.00078±.00001

Hence,

From ratio—	
2	Fe = 55.824±.00068
3	55.828±.00095
1	55.854±.00093
7	56.042±.0532
4	56.089±.1144
6	56.216±.0026
5	56.226±.0428
General mean	Fe = 55.846±.00047

[1] Journ. Amer. Chem. Soc., 33, 337. 1911.

Rejection of the four highest values lowers the atomic weight of iron to 55.833. The true value probably lies between this and the general mean as found.

NICKEL AND COBALT.

On account of the close similarity of these metals to each other, their atomic weights, so nearly identical, have received of late years much attention.

The first determinations, and the only ones up to 1852, were made by Rothhoff,[1] each with but a single experiment. For nickel 188 parts of the monoxide were dissolved in hydrochloric acid; the solution was evaporated to dryness, the residue was dissolved in water, and precipitated by silver nitrate; 718.2 parts of silver chloride were thus formed; whence, Ni = 59.05. The same process was applied also to cobalt, 269.2 parts of the oxide being found equivalent to 1,029.9 of AgCl; hence, Co = 58.93. These values are so nearly equal that their differences were naturally ascribed to experimental errors. They are, however, entitled to no special weight at present, since it can not be certain from any evidence recorded that the oxide of either metal was absolutely free from traces of the other.

In 1852 Erdmann and Marchand[2] published some figures, but without details, concerning the atomic weight of nickel. They reduced the oxide by heating in a current of hydrogen, and obtained values ranging from 58.2 to 58.6, when O = 16.

In 1856, incidentally to other work, Deville[3] found that 100 parts of metallic nickel yielded 262 of sulphate; whence Ni = 59.26.

To none of the foregoing estimations can any importance now be attached. The modern discussion of the atomic weights under consideration began with the researches of Schneider[4] in 1857. This chemist examined the oxalates of both metals, determining carbon by the combustion of the salts with copper oxide in a stream of dry air. The carbon dioxide thus formed was collected as usual in a potash bulb, which, in weighing, was counterpoised by a similar bulb, so as to eliminate errors due to the hygroscopic character of the glass. The metal in each oxalate was estimated, first by ignition in a stream of dry air, followed by intense heating in hydrogen. Metallic nickel or cobalt was left behind in good condition for weighing. Four analyses of each oxalate were made, with the results given below. The nickel salt contained three molecules of water and the cobalt salt two molecules.

$NiC_2O_4.3H_2O$.	CO_2.	*Per cent.*
1.1945	0.528	44.203
2.5555	1.12625	44.072
3.199	1.408	44.014
5.020	2.214	44.104
		Mean, 44.098±.027

The following percentages of nickel were found in this salt:

29.107	29.066
29.082	29.082

Mean, 29.084. ±006

$CoC_2O_4.2H_2O$.	CO_2.	*Per cent.*
1.6355	0.781	47.753
1.107	.5295	47.832
2.309	1.101	47.683
3.007	1.435	47.722
		Mean, 47.7475±.0213

The following were the percentages found for cobalt:

32.552	32.528
32.619	32.523

Mean, 32.555±.0149

[1] Cited by Berzelius. Poggend. Annalen, 8, 184. 1826.
[2] Journ. prakt. Chem., 55, 202. 1852.
[3] Ann. Chim. Phys. (3), 46, 182. 1856.
[4] Poggend. Annalen, 101, 387. 1857.

In a later paper[1] Schneider also gives someresu lts obtained with a nickel oxalate containing but two molecules of water. This gave him 47.605 per cent of CO_2, and the following percentages of nickel:

31.4115
31.4088

Mean, 31.4076±.0026

The conclusion at which Schneider arrived was that the atomic weights of cobalt and nickel are not identical, being about 60 and 58, respectively.

These analyses of the oxalates are now of little value for determining the atomic weight of two metals. Used directly, they give aberrant results; but by computing from the cross ratio between the nickel or cobalt and the carbon dioxide, more nearly concordant values are obtainable. With nickel the ratio $2CO_2$ to Ni gives for the trihydrate Ni = 58.042, and for the dihydrate Ni = 58.062. These figures are now known to be much too low. From cobalt oxalate, similarly computed, Co = 60.004, a value which is certainly too high.

The next chemist to take up the discussion of these atomic weights was Marignac, in 1858.[2] He worked with the chlorides and sulphates of nickel and cobalt, using various methods, but publishing few details, as he did not consider the determinations final. The sulphates, taken as anhydrous, were calcined to oxides. From the ration $NiSO_4$: NiO, he found Ni = 58.4 to 59.0, and from five measurements of the ratio $CoSO_4$: Co, Co = 58.64 to 58.76. If oxygen is taken as 16, these give for the percentages of oxide in the sulphate:

CoO in $CoSO_4$.	*NiO in $NiSO_4$.*
48.267	48.187
48.307	48.387
Mean, 48.287±.0135	Mean, 48.287±.0675
Hence, Co = 58.76.	Hence, Ni = 58.76.

The chlorides were dried at 100°, but found to retain water; and in most cases were then either fused in a stream of chlorine or of dry, gaseous hydrochloric acid, or else calcined gently with ammonium chloride. The determinations were then made by titration with a standard solution of silver in nitric acid. Five experiments with anhydrous $CoCl_2$ gave Co = 58.72 to 58.84. Three more with $CoCl_2$ dried at 100° gave Co = 58.84 to 59.02. Three with anhydrous $NiCl_2$ gave Ni = 58.80 to 59.00. If the calculations were made with Ag = 108 and Cl = 35.5, then these data give as proportional to 100 parts of silver:

$NiCl_2$.	*$CoCl_2$.*
60.093	60.056
60.185	60.111
	60.111
	60.194
Mean, 60.139±.0310	Mean, 60.118±.0192
Hence, Ni = 58.83.	Hence, Co = 58.79.

In one more experiment $NiCl_2$ was precipitated with a known quantity of silver. The filtrate was calcined, yielding NiO; hence the ratio 2Ag : NiO, giving Ni = 59.29. This experiment needs no farther attention.

In short, according to Marignac, and contrary to Schneider's views, the two atomic weights are approximately the same. Marignac criticises Schneider's earlier paper, holding that the nickel oxalate may have contained some free oxalic acid, and that the cobalt salt was possibly contaminated with carbonate or with basic compounds. In his later papers Schneider rejects these suggestions as unfounded, and in turn criticises Marignac. The purity of anhydrous $NiSO_4$ is not easy to guarantee, and, according to Schneider, the anhydrous chlorides of cobalt and nickel are liable to be contaminated with oxides. This is the case even when the chlorides are heated in chlorine, unless the gas is carefully freed from all traces of air and moisture.

[1] Poggend. Annalen, 107, 616. [2] Arch. Sci. Phys. Nat., nouv. série, 1372. 1858. Œuvres Complètes, 1, 575.

Dumas'[1] determinations of the two atomic weights were made with the chlorides of nickel and cobalt. The pure metals were dissolved in aqua regia, the solutions were repeatedly evaporated to dryness, and the residual chlorides were ignited in dry hydrochloric acid gas. The last two estimations in the nickel series were made upon $NiCl_2$ formed by heating the spongy metal in pure chlorine. In the third column I give the $NiCl_2$ or $CoCl_2$ equivalent to 100 parts of silver:

$NiCl_2$.	*Ag.*	*Ratio.*
0.9123	1.515	60.218
2.295	3.8115	60.212
3.290	5.464	60.212
1.830	3.041	60.179
3.001	4.987	60.176
		Mean, 60.1992±.0062

Hence, Ni = 58.96.

$CoCl_2$.	*Ag.*	*Ratio.*
2.352	3.9035	60.254
4.210	6.990	60.229
3.592	5.960	60.268
2.492	4.1405	60.186
4.2295	7.0255	60.202
		Mean, 60.2278±.011

Hence, Co = 58.79.

These values for Co and Ni differ by less than a tenth of a unit; here, as elsewhere, the figure for Ni being a trifle the lower.

Combining these data for nickel with Marignac's series, we have—

$$2Ag : NiCl_2 : : 100 : x$$

Marignac	60.139±.0310
Dumas	60.199±.0062
General mean	60.194±.0061

The cobalt figures will be combined with others later.

In 1863[2] the idea that nickel and cobalt have equal atomic weights was strengthened by the researches of Russell. He found that the black oxide of cobalt, by intense heating in an atmosphere of carbon dioxide, became converted into a brown monoxide of constant composition. The ordinary oxide of nickel, on the other hand, was shown to be convertible into a definite monoxide by simple heating over the blast lamp. The pure oxides of the two metals, thus obtained, were reduced by ignition in hydrogen, and their exact composition thus ascertained. Several samples of each oxide were taken, yielding the following data. The separate samples are indicated by lettering:

Nickel.

	NiO.	*Ni.*	*Per cent Ni.*
A	2.0820	1.6364	78.597
	2.0956	1.6468	78.584
	2.0148	1.5838	78.608
B	2.2069	1.7342	78.581
	2.2843	1.7952	78.589
	2.1329	1.6761	78.583
C	2.2783	1.7911	78.616
	2.1434	1.6845	78.590
	2.4215	1.9030	78.588
D	2.1859	1.7179	78.590
	2.0088	1.5788	78.594
	2.0839	1.6379	78.597
	2.6560	2.0873	78.588
			Mean, 78.593±.0018

[1] Ann Chem. Pharm., 113, 25. 1860.

[2] Journ. Chem. Soc. (2), 1, 51. 1863.

Cobalt.

	CoO.	*Co.*	*Per cent Co.*
A	2.1211	1.6670	78.591
	2.0241	1.5907	78.588
	2.1226	1.6673	78.550
	1.9947	1.5678	78.598
	3.0628	2.4078	78.614
B	2.1167	1.6638	78.603
	1.7717	1.3924	78.591
	1.7852	1.4030	78.591
C	1.6878	1.3264	78.588
	2.2076	1.7350	78.592
D	2.6851	2.1104	78.597
	2.1461	1.6868	78.598
E	3.4038	2.6752	78.595
	2.2778	1.7901	78.589
	2.1837	1.7163	78.596
			Mean, 78.592±.0023

These percentages are practically identical, and lead to essentially the same mean value for each atomic weight, namely,

$$Ni = 58.742$$
$$Co = 58.738$$

In a later paper Russell[1] confirmed the foregoing results by a different process. He dissolved metallic nickel and cobalt in hydrochloric acid and measured the hydrogen evolved. Thus the ratio between the metal and his ultimate standard was fixed without the intervention of any other element. About two-tenths of a gramme of metal, or less, was taken in each experiment. The data obtained were as follows; the last column giving the weight of hydrogen, computed from its volume, yielded by 100 parts of cobalt or nickel:

Nickel.

	Wt. Ni.	*Vol. H in cc.*	*Ratio.*
A	.0906	153.62	3.420
	.1017	172.32	3.418
	.1990	337.06	3.416
	.0997	168.93	3.417
	.1891	319.86	3.412
	.1859	314.75	3.415
	.1838	311.25	3.416
B	.1892	318.75	3.398
	.1806	305.28	3.409
	.2026	333.81	3.404
C	.1933	325.93	3.401
D	.1890	319.77	3.412
	.1942	328.15	3.408
	.1781	301.09	3.410
			Mean, 3.411±.001

Cobalt.

	Wt. Co.	*Vol. H in cc.*	*Ratio.*
A	.1958	321.36	3.395
	.1905	312.95	3.398
	.1946	319.63	3.397
	.2002	328.96	3.398
B	.1996	328.43	3.403
	.2000	329.55	3.401
	.1721	290.17	3.401
C	.1877	308.97	3.404
	.1935	318.60	3.405
D	.1909	314.73	3.410
	.1834	305.40	3.407
			Mean, 3.4017±.0009

[1] Journ. Chem. Soc. (2), 7, 294. 1869.

The weight of the hydrogen in these determinations was doubtless computed from Regnault's figures for the density of that gas. Correcting by the new value for the weight of a liter of hydrogen, 0.089872 gramme, the ratios become:

For nickel	3.4211±.0010
For cobalt	3.4112±.0009

Hence, Ni = 58.92 and Co = 59.09.

Some time after the publication of Russell's first paper, but before the appearance of his second, some other investigations were made known. Of these the first was by Sommaruga,[1] whose results, obtained by novel methods, closely confirmed those of Schneider and antagonized those of Dumas, Marignac, and Russell. The atomic weight of nickel Sommaruga deduced from analyses of the nickel potassium sulphate, $K_2Ni(SO_4)_2.6H_2O$, which, dried at 100°, has a perfectly definite composition. In this salt the sulphuric acid was determined in the usual way as barium sulphate, a process to which there are obvious objections. In the third column are given the quantities of the nickel salt proportional to 100 parts of $BaSO_4$:

Sulphate	*$BaSO_4$.*	*Ratio.*
0.9798	1.0462	93.653
1.0537	1.1251	93.654
1.0802	1.1535	93.645
1.1865	1.2669	93.654
3.2100	3.4277	93.649
3.2124	3.4303	93.648
		Mean, 93.6505±.001

Hence, Ni = 58.79.

For cobalt Sommaruga used the purpureocobalt chloride of Gibbs and Genth. This salt, dried at 110°, is anhydrous and stable. Heated hotter, $CoCl_2$ remains. The latter, ignited in hydrogen, yields metallic cobalt. In every experiment the preliminary heating must be carried on cautiously until ammoniacal fumes no longer appear:

Chloride	*Co.*	*Per cent.*
0.6656	0.1588	23.858
1.0918	.2600	23.814
.9058	.2160	23.846
1.5895	.3785	23.813
2.9167	.6957	23.847
1.8390	.4378	23.806
2.5010	.5968	23.808
		Mean, 23.827±.006

Hence, Co = 59.91.

Further along this series will be combined with a similar one by Lee. It may here be said that Sommaruga's paper was quickly followed by a critical essay from Schneider,[2] indorsing the former's work and objecting to the results of Russell.

In 1867 still another new process for the estimation of these atomic weights was put forward by Winkler,[3] who determined the amount of gold which pure metallic nickel and cobalt could precipitate from a neutral solution of sodio-auric chloride.

In order to obtain pure cobalt Winkler prepared purpureocobalt chloride, which, having been four or five times recrystallized, was ignited in hydrogen. His nickel was repeatedly purified by precipitation with sodium hypochlorite. From material thus obtained pure nickel chloride was prepared, which, after sublimation in dry chlorine, was also reduced by hydrogen. One hundred parts of gold are precipitated by the quantities of nickel and cobalt given in the third columns, respectively. In the cobalt series I include one experiment by Weselsky, which was published by him in a paper presently to be cited:

Ni.	*Au.*	*Ratio.*
0.4360	0.9648	45.191
.4367	.9666	45.179
.5189	1.1457	45.291
.6002	1.3286	45.175
		Mean, 45.209±.019

[1] Sitzungsb. Wien. Akad., 54, 2 Abth., 50. 1866. [2] Poggend. Annalen, 130, 310. [3] Zeit. anal. Chem., 6, 18. 1867.

Hence, Ni = 59. 44.

Co.	*Au.*	*Ratio.*
.5890	1. 3045	45. 151
.3147	.6981	45. 080
.5829	1. 2913	45. 141
.5111	1. 1312	45. 182
.5821	1. 2848	45. 307
.559	1. 241	45. 044—Weselsky
		Mean, 45. 151 ± 025

Hence, Co = 59. 36.

Weselsky's paper,[1] already quoted, relates only to cobalt. He ignited the cobalticyanides of ammonium and of phenylammonium in hydrogen, and from the determinations of cobalt thus made deduced its atomic weight. His results are as follows:

0. 7575 grm. $(NH_4)_6Co_2Cy_{12}$	gave 0. 166 grm.	Co.	21. 914 per cent.
.5143 "	.113 "		21. 972 "
		Mean,	21. 943 ± .029

Hence, Co = 59.09

$(C_6H_8N)_6Co_2Cy_{12}$	*Co.*	*Per cent.*
0. 8529	0. 1010	11. 842
.6112	.0723	11. 829
.7140	.0850	11. 905
.9420	.1120	11. 890
		Mean, 11. 8665 ± .0124

Hence, Co = 59. 02.

Next in order is the work done by Lee [2] in the laboratory of Wolcott Gibbs. Like Weselsky, Lee ignited certain cobalticyanides and also nickelocyanides in hydrogen and determined the residual metal. The double cyanides chosen were those of strychnia and brucia, salts of very high molecular weight, in which the percentages of metal are relatively low. A series of experiments with purpureocobalt chloride was also carried out. In order to avoid admixture of carbon in the metallic residues, the salts were first ignited in air, and then in oxygen. Reduction by hydrogen followed. The salts were in each case covered by a porous septum of earthenware, through which the hydrogen diffused, and which served to prevent the mechanical carrying away of solid particles; furthermore, heat was applied from above. The results attained appeared to be satisfactory, and assign to nickel and cobalt atomic weights varying from each other by about a unit; Ni being nearly 58, and Co about 59, when O = 16. The cobalt results agree remarkably well with those of Weselsky. The following are the data obtained:

Brucia nickelocyanide, $Ni_3Cy_{12}(C_{23}H_{26}N_2O_4)_6H_6.10H_2O$.

Salt.	*Ni.*	*Per cent Ni.*
0. 3966	0. 0227	5. 724
.5638	.0323	5. 729
.4000	.0230	5. 750
.3131	.01795	5. 733
.4412	.0252	5. 712
.4346	.0249	5. 729
		Mean, 5. 7295 ± .0034

Hence, Ni = 58.022.

Strychnia nickelocyanide, $Ni_3Cy_{12}(C_{21}H_{22}N_2O_2)_6H_6.8H_2O$.

Salt.	*Ni.*	*Per cent Ni.*
0. 5358	0. 0354	6. 607
.5489	.0363	6. 613
.3551	.0234	6. 589
.4495	.0297	6. 607
.2530	.0166	6. 561
.1956	.0129	6. 595
		Mean, 6. 595 ± .005

Hence, Ni = 58. 079.

[1] Ber. Deutsch. chem. Gesell., 2, 592. 1868.

[2] Amer. Journ. Sci. (3), 2, 44. 1871.

Brucia cobalticyanide, $Co_2Cy_{12}(C_{23}H_{26}N_2O_4)_6H_6.\ 20H_2O$.

Salt.	*Co.*	*Per cent Co.*
0.4097	0.0154	3.759
.3951	.0147	3.720
.5456	.0204	3.739
.4402	.0165	3.748
.4644	.0174	3.747
.4027	.0151	3.749
		Mean, 3.7437±.0036

Hence, Co = 59.20.

Strychnia cobalticyanide, $Co_2Cy_{12}(C_{21}H_{22}N_2O_2)_6H_6.8H_2O$.

Salt.	*Co.*	*Per cent Co.*
0.4255	0.0195	4.583
.4025	.0185	4.596
.3733	.0170	4.554
.4535	.0207	4.564
.2753	.0126	4.577
.1429	.0065	4.549
		Mean, 4.5705±.005

Hence, Co = 59.10.

Purpureocobalt chloride, $Co_2(NH_3)_{10}Cl_6$.

Salt.	*Co.*	*Per cent Co.*
0.9472	0.2233	23.575
.8903	.2100	23.587
.6084	.1435	23.586
.6561	.1547	23.579
.6988	.1647	23.569
.7010	.1653	23.581
		Mean, 23.5795±.0019

Hence, Co = 59.099.

The last series may be combined with Sommaruga's, thus:

Sommaruga	23.827 ±.006
Lee	23.5795±.0019
General mean	23.6045±.0018

Baubigny's [1] determinations of the atomic weight of nickel are limited to two experiments upon the calcination of nickel sulphate, and his data are as follows:

$NiSO_4$.	*NiO.*	*Per cent.*
6.2605	3.0225	48.279
4.4935	2.1695	48.281
		Mean, 48.280

Hence, Ni = 58.741.

Zimmerman's work, published after his death by Krüss and Alibegoff,[2] was based, like Russell's, upon the reduction of cobalt and nickel oxides in hydrogen. The materials used were purified with great care, and the results were as follows:

Nickel.

NiO.	*Ni.*	*Per cent Ni.*
6.0041	4.7179	78.578
6.4562	5.0734	78.582
8.5960	6.7552	78.585
4.7206	3.7096	78.583
8.2120	6.4536	78.587
9.1349	7.1787	78.585
10.0156	7.8702	78.579
4.6482	3.6526	78.580
8.9315	7.0184	78.580
10.7144	8.4196	78.582
3.0036	2.3602	78.579
		Mean, 78.582±.0006

Hence, Ni = 58.704.

[1] Compt. Rend., 97, 951. 1883.

[2] Ann. Chem., 232, 324. 1886.

Cobalt.

CoO.	*Co.*	*Per cent Co.*
6. 3947	5. 0284	78. 634
6. 6763	5. 2501	78. 638
5. 6668	4. 4560	78. 633
2. 9977	2. 3537	78. 637
8. 7446	6. 8763	78. 635
3. 2625	2. 5655	78. 636
6. 3948	5. 0282	78. 630
8. 2156	6. 4606	78. 638
9. 4842	7. 4580	78. 636
9. 9998	7. 8630	78. 632
		Mean, 78. 635±. 0002

Hence, Co = 58.889.

Shortly after the discovery of nickel carbonyl, NiC_4O_4, Mond, Langer, and Quincke [1] made use of it with reference to the atomic weight of nickel. The latter was purified by distillation as nickel carbonyl, then converted into oxide, and that was reduced by hydrogen in the usual way.

NiO.	*Ni.*	*Per cent Ni.*
0. 2414	0. 1896	78. 542
. 3186	. 2503	78. 562
. 3391	. 2663	78. 531
		Mean, 78. 545±. 0061

Hence, Ni = 58.575.

Schutzenberger's experiments,[2] published in 1892, were also few in number. First, nickel sulphate, dehydrated at 440°, was calcined to oxide.

$NiSO_4$.	*NiO.*	*Per cent.*
3. 505	1. 690	48. 217
2. 6008	1. 2561	48. 297
		Mean, 48. 257±. 027

Hence, Ni = 58.671.

Secondly, nickel oxide was reduced in hydrogen, as follows:

NiO.	*Ni.*	*Per cent.*
1. 6865	1. 3245	78. 535
1. 2527	. 9838	78. 533
		Mean, 78. 534

Hence, Ni = 58.536.

In one experiment with cobalt oxide 3.491 grm. gave 2.757 Co., or 78.975 per cent. Hence, Co = 60.1. In view of the many determinations of this ratio by other observers, this single estimation may be neglected. The experiments on nickel sulphate, however, should be combined with those of Marignac and Baubigny, giving the latter equal weight with Schutzenberger's, thus:

Marignac	48. 287±. 0675
Baubigny	48. 280±. 027
Schutzenberger	48. 257±. 027
General mean	48. 269±. 018

From this point on the determination of these atomic weights was temporarily complicated by the questions raised by Krüss as to the truly elementary character of nickel and cobalt. If that which has been called nickel really contains an admixture of some other hitherto unknown element, then all the determinations made so far are worthless, and the investigations now to be considered bear directly upon that question. First in order comes Remmler's research upon cobalt.[3] This chemist, asking whether cobalt is homogeneous,

[1] Journ. Chem. Soc., 57, 753. 1890.
[2] Compt. Rend., 114, 1149. 1892.
[3] Zeit. anorg. Chem., 2, 221. Also more fully in an Inaugural Dissertation, Erlangen, 1891

prepared cobaltic hydroxide in large quantity and made a series of successive ammoniacal extracts from it, 25 in all. Each extract represented a fraction, from which, by a long series of operations, cobalt monoxide was prepared, and the latter was reduced in hydrogen after the manner of Russell. The actual determinations began with the second fraction. and the data are subjoined, the number of the fraction being given with each experiment:

	CoO.	*Co.*	*Per cent Co.*
2	0.09938	0.07837	78.859
3	.15021	.11814	78.650
4	.22062	.17360	78.687
5	.39011	.30681	78.647
6	.28820	.22661	78.629
7	.34304	.26968	78.615
8	.43703	.34321	78.532
9	.91477	.71864	78.560
10	.63256	.49661	78.508
11	.32728	.25701	78.529
12	.38042	.29899	78.595
13	.16580	.13027	78.571
14	1.01607	.79873	78.610
15	1.31635	1.03545	78.661
16	.91945	.72315	78.650
17	.53100	.41773	78.668
18	.82381	.64728	78.572
19	.81139	.63754	78.574
20	.76698	.60292	78.610
21	1.13693	.89412	78.643
22	2.00259	1.57495	78.646
23	1.04629	.82185	78.549
24	.48954	.38466	78.576
25	.69152	.54326	78.560
			Mean, 78.613±.0099

Hence, Co = 58.812.

Considered with reference to the purpose of the investigation, this mean and its probable error have no real significance. But it is very close to the mean of other experimenters, and a study of the variations represented by the several fractions seems to indicate fortuity rather than system. Remmler regards his results as indicating lack of homogeneity in his material; but it seems more probable that such differences as exist are due to experimental errors and to impurities acquired in the long process of purification to which each fraction was submitted rather than to any uncertainty regarding the nature of cobalt itself.

From the same point of view—that is, with reference to the supposed heterogeneity of nickel—Krüss and Schmidt [1] carried out a series of fractionations of the metal by distillation in a stream of carbon monoxide. Nickel oxide, free from obnoxious impurities, was first reduced to metal by heating in hydrogen, after which the current of carbon monoxide was allowed to flow. The latter, carrying its small charge of nickel tetracarbonyl was then passed through a Winkler's absorption apparatus containing pure aqua regia, from which, by evaporation, nickel chloride was obtained, and from that, by reduction in hydrogen, the nickel. Ten such fractions were successively prepared and studied; first, by preparation of NiO and its reduction in hydrogen; and, secondly, in some cases, by the reoxidation of the reduced metal, so as to give a synthetic value for the ratio Ni : O. The data obtained are as follows, the successive fractions being numbered:

Reduction of NiO.

	NiO.	*Ni.*	*Per cent Ni.*
1	0.3722	0.2926	78.614
1	.7471	.5870	78.571
2	.7659	.60085	78.450
2	.7606	.5961	78.372

[1] Zeit. anorg. Chem., 2, 235. 1892.

	NiO.	*Ni.*	*Per cent Ni.*
3	1.0175	.7984	78.467
	1.2631	.99065	78.430
	1.2582	.9868	78.429
4	.5193	.4076	78.490
	.9200	.7215	78.424
5	.4052	.3179	78.455
	.6518	.5111	78.414
6	.5623	.4399	78.232
	.5556	.4350	78.294
7	.9831	.7724	78.568
	.9765	.7646	78.300
	.9639	.7557	78.400
8	.5756	.4538	78.839
	.56765	.4451	78.411
	.5663	.4438	78.368
	.5449	.4272	78.400
9	.3174	.2491	78.481
	.3148	.2467	78.367
10	.4976	.3904	78.457
	.4961	.3891	78.432

Mean, 78.444±.0166

Hence, Ni = 58.225.

Oxidation of Ni.

	Ni.	*NiO.*	*Per cent Ni.*
1	.5870	.7471	78.571
2	.6011	.7659	78.372
	.5961	.7606	78.359
3	.7988	1.0175	78.506
	.9913	1.2631	78.482
	.9868	1.2582	78.429
4	.4093	.5193	78.818
	.7216	.9200	78.435
5	.3194	.4052	78.825
	.5111	.6518	78.414
6	.4415	.5623	78.517
	.4350	.5556	78.294
7	.7752	.9831	78.853
	.7667	.9765	78.515
	.7558	.9639	78.411
8	.4555	.5756	79.135
	.4456	.56765	78.499
	.44415	.5663	78.430
	.4423	.5642	78.394
9	.2508	.3174	79.015
	.2467	.3148	78.367
10	.3918	.4976	78.738
	.3891	.4961	78.432

Mean, 78.557±.0319

Hence, Ni = 58.616.

To these data of Krüss and Schmidt the remarks already made concerning Remmler's work seem also to apply. The variations appear to be fortuitous, and not systematic, although the authors seem to think that they indicate a compositeness in that substance which has been hitherto regarded as elementary nickel. In view of all the evidence, however, I prefer to regard their varying estimations as affected by accidental errors, and to treat their means like others.

In 1889 Winkler[1] published a short paper concerning the gold method for determining the atomic weights in question, but gave in it no actual measurements. In 1893[2] he returned to the

[1] Ber. Deutsch. chem. Gesell., 22, 891. 1889.

[2] Zeit. anorg. Chem., 4, 10. 1893.

problem with a new line of attack, and at the same time he took occasion to criticize Krüss and Schmidt somewhat severely. He utterly rejects the notion that either nickel or cobalt contain any hitherto unknown element, and ascribes the peculiar results obtained by Krüss and Schmidt to impurities derived from the glass apparatus used in their experiments. For his own part he now works with pure nickel and cobalt precipitated electrolytically upon platinum, and avoids the use of glass or porcelain vessels so far as possible. With material thus obtained he operates by two distinct but closely related methods, both starting with the metal, nickel or cobalt, converting it next into neutral chloride, and then measuring the chloride gravimetrically in one process, volumetrically in the other.

After precipitation in a platinum dish the nickel or cobalt is washed with water, rinsed with alcohol and ether, and then weighed. It is next dissolved in pure hydrochloric acid, properly diluted, and by evaporation to dryness and long heating to 150° converted into anhydrous chloride. The nickel chloride thus obtained dissolves perfectly in water, but the cobalt salt always gave a slight residue in which the metal was electrolytically determined and allowed for. In the redissolved chloride, by precipitation with silver nitrate, silver chloride is obtained, giving a direct ratio between that compound and the nickel or cobalt originally taken. The gravimetric data are as follows, with the metal equivalent to 100 parts of silver chloride given in a final column:

Nickel.

Ni.	*AgCl.*	*Ratio.*
0.3011	1.4621	20.594
.2242	1.0081	20.605
.5166	2.5108	20.570
.4879	2.3679	20.605
.3827	1.8577	20.601
.3603	1.7517	20.568
		Mean, 20.590±.0049

Hence, Ni = 59.03.

Cobalt.

Co.	*AgCl.*	*Ratio.*
0.3458	1.6596	20.836
.3776	1.8105	20.856
.4493	2.1521	20.877
.4488	2.1520	20.855
.2856	1.3683	20.873
.2648	1.2768	20.886
		Mean, 20.864±.0050

Hence, Co = 59.81.

In the volumetric determinations the neutral chloride, prepared as before, was decomposed by means of a slight excess of potassium carbonate, and in the potassium chloride solution, after removal of the nickel or cobalt, the chlorine was measured by titration by Volhard's method with a standard solution of silver. The amount of silver thus used was comparable with the metal taken.

Nickel.

Ni.	*Ag.*	*Ratio.*
0.1812	0.6621260	27.366
.1662	.6079206	27.339
.2129	.7775252	27.382
.2232	.8162108	27.346
.5082	1.8556645	27.386
.1453	.5315040	27.338
		Mean, 27.359±.0059

Hence, Ni = 59.03.

Cobalt.

Co.	*Ag.*	*Ratio*
0.177804	0.6418284	27.702
.263538	.9514642	27.699
.245124	.8855780	27.679
.190476	.6866321	27.741
.266706	.9629146	27.696
.263538	.9503558	27.731
		Mean, 27.708±.0064

In view of the possibility that the cobalt chloride of the foregoing experiments might contain traces of basic salt Winkler, in a supplementary investigation,[1] checked them by another process. To the electrolytic cobalt, in a platinum dish, he added a quantity of neutral silver sulphate and then water. The cobalt gradually went into solution, and metallic silver was precipitated. The weights were as follows:

Co.	*Ag.*
0.2549	0.9187
.4069	1.4691

On examination of the silver it was found that traces of cobalt were retained—less than 0.5 mg. in the first determination and less than 0.2 mg. in the second. Taking these amounts as corrections the two experiments give for the ratio 2Ag : Co :: 100 : x the subjoined values:

27.706
27.687

These figures confirm those previously found, and as they fall within the limits of the preceding series, they may fairly be included in it, when all eight values give a mean of 27.705±.0050. Hence, Co = 59.78.

Still another method, radically different from all of the foregoing processes, was adopted by Winkler in 1894.[2] The metals were thrown down electrolytically upon platinum, and so weighed. Then they were treated with a known excess of a decinormal solution of iodine in potassium iodide, which redissolved them as iodides. The excess of free iodine was then determined by titration with sodium thiosulphate, and in that way the direct ratio between metal and haloid was ascertained. The results were as follows, with the metal proportional to 100 parts of iodine given in the third column:

Cobalt.

	Wt. Co.	*Wt. I.*	*Ratio.*
First series	.4999	2.128837	23.482
	.5084	2.166750	23.463
	.5290	2.254335	23.466
	.6822	2.908399	23.456
	.6715	2.861617	23.466
Second series	.5185	2.209694	23.465
	.5267	2.246037	23.450
	.5319	2.268736	23.445
			Mean, 23.462±.0027

Hence, Co = 59.57.

Nickel.

	Wt. Ni.	*Wt. I.*	*Ratio.*
First series	.5144	2.217494	23.251
	.4983	2.148502	23.246
	.5265	2.268742	23.260
	.6889	2.970709	23.243
	.6876	2.965918	23.237
Second series	.5120	2.205627	23.267
	.5200	2.240107	23.267
	.5246	2.259925	23.267
			Mean, 23.255±.0091

Hence, Ni = 59.03.

[1] Zeit. anorg. Chem., 4, 462. 1893.

[2] Zeitsch. anorg. Chem., 8, 1. 1894.

In these experiments, as well as in some previous series, a possible source of error is to be considered in the occlusion of hydrogen by the metals. Accordingly, in a supplementary paper, Winkler [1] gave the results of some check experiments made with iron, which, however, was not absolutely pure. His conclusion is that the error, if existent, must be very small.

In 1895 Hempel and Thiele's work on cobalt appeared.[2] First, cobalt oxide, prepared from carefully purified materials, was reduced in hydrogen. The weights of metal and oxygen are subjoined, with the percentage of cobalt in the oxide deduced from them:

Co.	*O.*	*Percentage.*
0.90068	0.24429	78.664
.79159	.21445	78.686
1.31558	.35716	78.648
		Mean, 78.666±.0074

Hence, Co=58.998.

In their next series of experiments, excluding a rejected series, Hempel and Thiele weighed cobalt, converted it into anhydrous chloride, and noted the gain in weight. In four of the experiments the chloride was afterwards dissolved, precipitated with silver nitrate, and then the silver chloride was weighed. The data are as follows:

Co.	*Cl taken up.*	*AgCl.*
0.7010	0.8453	.....
.3138	.3793	.....
.2949	.3562	1.4340
.4691	.5657	2.2812
.5818	.7026	2.8303
.5763	.6947	.....
.5096	.6142	2.4813

From these weights we get two ratios, thus:

$Cl_2 : Co :: 100 : x.$	$2AgCl : Co :: 100 : x.$
82.929	20.565
82.731	20.564
82.791	20.556
82.924	20.538
82.807	
82.957	Mean, 20.556±.0043
82.970	
Mean, 82.873±.0241	

Hence, Co=58.77. Hence, Co=58.93.

The second of these ratios was also measured by Winkler, and the two series combine as follows:

Winkler	20.864±.0050
Hempel and Thiele	20.556±.0043
General mean	20.687±.0033

Hempel and Thiele apply to it a correction for silver chloride retained in solution, but its amount is small and not altogether certain. For present purposes the correction may be neglected.

The atomic weight of nickel was determined by Richards and Cushman [3] from analyses of nickel bromide. This salt, as first prepared, contained traces of oxide, which are to be deducted from the halide compound. In a preliminary series of experiments the following figures were obtained, representing vacuum weights:

$NiBr_2$.	*AgBr.*	*Insoluble, mg.*	*Ratio.*
2.26113	3.88769	3.22	58.161
2.80668	4.82431	7.08	58.178
1.41317	2.42880	3.05	58.184
1.71759	2.95307	.88	58.163
2.48565	4.27357	5.24	58.163
4.32997	7.44280	15.83	58.177
2.18072	3.74856	.....	58.175
			Mean, 58.172±.0023

[1] Zeitsch. anorg. Chem., 8, 291. 1895. See preceding section of this work, on iron, for the detailed determinations.
[2] Zeitsch. anorg. Chem., 11, 73.
[3] Proc. Amer. Acad., 33, 97. 1897.

In the second set of analyses, both ratios were determined, namely, with silver and with silver bromide, by the standard methods. The data follow:

$NiBr_2$.	$AgBr$.	Ag.	*Ag ratio.*	*AgBr ratio.*
3.28039	5.63892	3.22910	101.275	58.174
2.70044	4.64208	2.66636	101.278	58.173
3.38230	5.81391	3.33990	101.270	58.176
1.33459	2.29435	1.31787	101.268	58.169
1.25054	2.14963	1.23482	101.273	58.175
1.32278	2.27384	1.30629	101.262	58.174
1.24452	2.85805	2.21652	101.263	58.177
			Mean, 101.270±.0015	58.174±.0007

This value for the AgBr ratio, combined with the preliminary series, gives a general mean of 55.1738±.0007.

From the Ag ratio, Ni=58.654.

From the AgBr ratio, Ni=58.658.

And Ag : Br :: 100 : 74.082.

In a second memoir,[1] Richards and Cushman describe a series of determinations based upon the reduction of nickel bromide by heating in hydrogen. The correcred data appear in the next table:

$NiBr_2$.	*Ni.*	*Per cent Ni.*
2.83325	0.76081	26.853
3.21625	.86358	26.851
2.31241	.62094	26.853
2.87953	.77330	26.855
2.29650	.61679	26.858
2.98893	.80272	26.856
5.51291	1.48056	26.856
2.24969	.60415	26.855
		Mean, 26.855±.0005

Hence, Ni=58.687.

In this series a correction was applied for traces of sodium bromide contained in the nickel salt. A similar correction, applied to the former series of determinations, would raise the atomic weight of nickel by 0.015.

The three memoirs upon cobalt, by Richards and Baxter,[2] contain data relative to the bromide, the chloride and the oxide. It is hardly necessary to state that all of the materials employed in the investigation were scrupulously purified, and that all weights were reduced to a vacuum. First, as in the case of nickel, the two silver ratios to the bromide were determined. A preliminary set of analyses gave results as follows:

$CoBr_2$.	$AgBr$.	*Ratio.*
2.25295	3.86818	58.243
2.88763	4.95732	58.250
1.88806	3.24056	58.263
		Mean, 58.252±.0040

The second and third series of analyses gave both ratios, and may be tabulated together:

$CoBr_2$.	$AgBr$.	Ag.	*Ag ratio.*	*AgBr ratio.*
1.33564	2.29296	1.31702	101.414	58.250
2.58129	4.43095	2.54585	101.392	58.256
2.84382	4.88135	2.80449	101.402	58.259
1.83722	3.15368	1.81170	101.409	58.256
2.68584	4.61046	2.64879	101.399	58.255
3.18990	5.47607	.....	.....	58.252
2.88914	4.95943	2.84891	101.412	58.255
2.32840	3.99706	2.29593	101.414	58.253
1.91703	3.29053	1.89033	101.413	58.259
			Mean, 101.407	58.255
			±.0018	±.0007

[1] Proc. Amer. Acad., 34, 327. 1899. This memoir contains a very full criticism of all the earlier work on nickel.

[2] Proc. Amer. Acad., 33, 115. 1897. *Ibid.*, 34, 351. 1899. *Ibid.*, 35, 61. 1899. For a criticism of Richards, Cushman, and Baxter, see Winkler Zeitsch. anorg. Chem., 17, 236. 1898.

The two series for the AgBr ratio, combined, give a weighted mean of 58.2549 ± .0007.
From the Ag ratio, Co = 58.950.
From the AgBr ratio, Co = 58.959.
And Ag : Br :: 100 : 74.075.

In their second memoir Richards and Baxter describe the reduction of cobalt bromide by heating in hydrogen. Three series of experiments were made, and in two of them a correction was necessary for small quantities of sodium bromide contained in the cobalt salt. In the following tables the corrected weights of cobalt bromide and cobalt are given

Series I.

$CoBr_2$.	Co.	Per cent Co.
5. 59023	1. 50680	26. 954
4. 61518	1. 24381	26. 950
3. 74498	1. 00920	26. 948
3. 00135	. 80899	26. 954
		Mean, 26. 951 ± .0010

Series II.

$CoBr_2$.	Co.	Per cent Co.
5. 32194	1. 43428	26. 950
7. 50786	2. 02321	26. 948
2. 32630	. 62677	26. 943
7. 44694	2. 00736	26. 956
		Mean, 26. 949 ± .0021

Series III.

$CoBr_2$.	Co.	Per cent Co.
5. 10891	1. 37721	26. 957
6. 41339	1. 72850	26. 951
6. 59805	1. 77876	26. 959
3. 02854	. 81606	26. 953
		Mean, 26. 953 ± .0021

The general mean of the three series is 26.9508 ± .0008. Hence Co = 58.973.

The third memoir of Richards and Baxter gives analyses of cobalt chloride and oxide. First, the chloride was reduced to metal by heating in hydrogen. Hempel and Thiele worked in the opposite direction, heating cobalt in chlorine and thereby effecting the synthesis of the compound. For uniformity of statement I give Richards and Baxter's series in the same form, as the ratio Cl_2 : Co : : 100 : x:

$CoCl_2$.	Co.	Ratio.
4. 16483	1. 89243	83. 279
2. 30512	1. 04723	83. 253
		Mean, 83. 266 ± .0087

Hence, Co = 59.053.

Hempel and Thiele's figures give for this ratio the figure 82.873 ± .0241. The general mean of both series is 83.220 ± .0082.

Five reductions of cobalt oxide in hydrogen are given, three in one series and two separate experiments with varied methods of manipulation. The results obtained are regarded by Richards and Baxter as unimportant, and they point out the difficulties of the process. Their data, arranged as one series, follow

CoO.	Co.	Per cent Co.
7. 04053	5. 53779	78. 656
6. 69104	5. 26312	78. 659
7. 83211	6. 15963	78. 646
7. 74240	6. 09219	78. 686
10. 58678	8. 32611	78. 646
		Mean, 78. 659 ± .0051

Hence, Co = 58.973.

This mean combines with former means as follows

Russell	78.592 ± .0023
Zimmermann	78.635 ± .0002
Remmler	78.613 ± .0099
Hempel and Thiele	78.666 ± .0074
Richards and Baxter	78.659 ± .0051
General mean	78.6324 ± .0002

Here Zimmermann's determinations practically appear alone.

The analyses of cobalt chloride by Baxter and Coffin[1] were made by the usual methods, as refined at Harvard University, and give the two silver ratios. The data, with vacuum weights, are as follows:

$CoCl_2$.	*Ag.*	*AgCl.*	*Ag ratio.*	*AgCl ratio.*
1.09959	1.82671	2.42676	60.195	45.311
1.47733	2.45398	3.26095	60.201	45.304
3.84133	6.38081	8.47735	60.201	45.313
3.64342	6.05232	.....	60.199	.....
2.96315	4.92244	6.54019	60.197	45.307
3.48418	5.78815	7.69084	60.195	45.303
3.29523	5.47410	7.27284	60.197	45.309
1.57655	2.61905	3.48012	60.195	45.302
			Mean, 60.1975	45.3070
			±.0006	±.0001

From the Ag ratio, Co = 58.961.

From the AgCl ratio, Co = 58.966.

And Ag : Cl : : 100 : 32.866.

For the silver ratio, 2Ag: $CoCl_2$: : 100 : x, there are two earlier sets of determinations. The three series combine as follows:

Marignac	60.118 ± .0192
Dumas	60.228 ± .0110
Baxter and Coffin	60.1975 ± .0006
General mean	60.1975 ± .0006

In this combination the older series vanish. Their influence is apparent only in the fifth decimal place.

The determinations of the atomic weight of nickel by Oechsner de Coninck and Gérard[2] are of slight importance, although they give a fairly good value for this constant. Nickel oxalate, $NiC_2O_4.2H_2O$, was reduced by heating in hydrogen, with the following results:

Oxalate.	*Ni.*	*Per cent Ni.*
0.4300	0.1380	32.093
.4730	.1517	32.072
.3440	.1104	32.093
.3869	.1241	32.075
.5161	.1656	32.087
		Mean, 32.084 ± .0030

Hence, Ni = 58.596.

Two sets of determinations of the atomic weight of nickel were made by Baxter and Parsons[3] in order to compare the ordinary metal with nickel obtained from meteoric iron. Nickel oxide was reduced by heating in hydrogen, with the following results. The weights are reduced to a vacuum.

[1] Journ. Amer. Chem. Soc., 28, 1580. 1906. Zeitsch. anorg. Chem., 51, 171.

[2] Compt. Rend., 158, 1345. 1914.

[3] Ann. Report, Carnegie Inst. Washington, 1915, 351.

1. *Terrestrial nickel.*

NiO.	*Ni.*	*Percent Ni.*
6.41281	5.03957	78.5860
6.10952	4.80102	78.5826
6.91023	5.43006	78.5800
4.60077	3.61528	78.5799
5.57122	4.37792	78.5810
5.59217	4.39445	78.5822
		Mean, 78.5819±.0007

Hence, Ni = 58.568.

2. *Meteoric nickel.*

NiO.	*Ni.*	*Percent Ni.*
6.65624	5.23021	78.5760
4.45609	3.50196	78.5882
4.64795	3.65212	78.5748
		Mean, 78.5797±.0009

Hence, Ni = 58.561.

These percentages combine with the earlier determinations as follows, Schutzenberger's measurements of the ratio being assigned equal weight with those of Mond, Langer, and Quincke:

Russell	78.593 ±.0018
Zimmermann	78.582 ±.0006
Mond, Langer, and Quincke	78.545 ±.0061
Schutzenberger	78.534 ±.0061
Krüss and Schmidt, reduction series	78.444 ±.0166
Krüss and Schmidt, oxidation series	78.557 ±.0319
Baxter and Parsons, 1	78.5819±.0007
Baxter and Parsons, 2	78.5797±.0009
General mean	78.576 ±.00046

After rejecting the analyses of the oxalate by Schneider, we have the following ratios for nickel to consider:

(1) Per cent of Ni in $NiC_2O_4.2H_2O$, 32.084±.0030.
(2) Per cent of Ni in brucia nickelocyanide, 5.7295±.0034.
(3) Per cent of Ni in strychnia nickelocyanide, 6.595±.005.
(4) Per cent of NiO in $NiSO_4$, 48.269±.018.
(5) Per cent of Ni in NiO, 78.576±.00046.
(6) $2Ag : NiCl_2 :: 100 : 60.194 \pm .0061$.
(7) $2AgCl : Ni :: 100 : 20.590 \pm .0049$.
(8) $2Ag : NiBr_2 :: 100 : 101.270 \pm .0015$.
(9) $2AgBr : NiBr_2 :: 100 : 58.1738 \pm .0007$.
(10) $NiBr_2 : Ni :: 100 : 26.855 \pm .0005$.
(11) $2Ag : Ni :: 100 : 27.359 \pm .0059$.
(12) $2Au : 3Ni :: 100 : 45.209 \pm .019$.
(13) $2BaSO_4 : K_2Ni(SO_4)_2.6H_2O :: 100 : 93.6505 \pm .001$.
(14) $Ni : H_2 :: 100 : 3.4211 \pm .001$.
(15) $I_2 : Ni :: 100 : 23.255 \pm .0091$.

The values used in reducing these ratios are—

Ag=107.880 ±.00016	C= 12.0025±.00019
Cl= 35.4605±.00011	N= 14.0081±.00008
Br= 79.9228±.00015	K= 39.0975±.00011
I=126.926 ±.00023	Ba=137.358 ±.0023
S= 32.0650±.00012	Au=197.209 ±.0029
H= 1.0078±.00001	

Hence,

From ratio—	
2	Ni=58.022±.0345
3	58.079±.0441
1	58.596±.0061
3	58.654±.0011
9	58.658±.0027
5	58.683±.0013
10	58.687±.0011
4	58.707±.0380
13	58.788±.0068
14	58.917±.0172
6	58.984±.0131
7	59.027±.0141
11	59.030±.0113
15	59.033±.0231
12	59.437±.0250
General mean	Ni=58.676±.00064

This mean lies within the limits of variation of Richards and Cushman's determinations, and may be regarded as satisfactory. Their work and Zimmermann's dominates the entire combination.

For cobalt we have eighteen ratios, as follows:

(1) Per cent. of Co in CoO, 78.6324 ± .0002
(2) Per cent. of Co in purpureocobalt chloride, 23.6045 ± .0018
(3) Per cent. of Co in phenylammonium cobalticyanide, 11.8665 ± .0124
(4) Per cent. of Co in ammonium cobalticyanide, 21.943 ± .029
(5) Per cent. of Co in brucia cobalticyanide, 3.7437 ± .0036
(6) Per cent. of Co in strychnia cobalticyanide, 4.5705 ± .005
(7) Per cent. of CoO in $CoSO_4$, 48.287 ± .0135
(8) $2Ag : CoCl_2 :: 100 : 60.1975 \pm .0006$
(9) $2AgCl : CoCl_2 :: 100 : 45.307 \pm .0011$
(10) $2Ag : Co :: 100 : 27.705 \pm .0050$
(11) $2AgCl : Co :: 100 : 20.687 \pm .0033$
(12) $Cl_2 : Co :: 100 : 83.220 \pm .0082$
(13) $2Ag : CoBr_2 :: 100 : 101.407 \pm .0018$
(14) $2AgBr : CoBr_2 :: 100 : 58.2549 \pm .0007$
(15) $CoBr_2 : Co :: 100 : 26.9508 \pm .0008$
(16) $2Au : 3Co :: 100 : 45.151 \pm .025$
(17) $Co : H_2 :: 100 : 3.4110 \pm .0009$
(18) $I_2 : Co :: 100 : 23.462 \pm .0027$

Hence, for the atomic weight of cobalt,

From ratio—	
7	Co=58.761±.0286
1	58.880±.0006
13	58.950±.0039
14	58.959±.0027
8	58.961±.0013
9	58.966±.0032
15	58.973±.0019
3	59.017±.0630
12	59.020±.0058
4	59.086±.0810
17	59.091±.0156
6	59.095±.0647
2	59.181±.0047
5	59.198±.0570
11	59.306±.0095

From ratio—

16	Co=59.361±.0330
18	59.569±.0069
10	59.776±.0108
General mean	Co=58.913±.0005

It is evident that in this combination, ratio 1, representing principally the work of Zimmermann, receives excessive weight. For that reason, and also on chemical grounds, the final mean is probably too low. If, however, we arbitrarily assign to ratio 1 the "probable error" and weight of the next best ratio, No.8, the general mean then becomes

$$Co = 58.956 \pm .0007$$

This is probably not far from the truth; but the change thus effected serves to illustrate the fact that the rigorous mathematical combination is not always conclusive. Although the mathematical method is most useful, it cannot do away with the exercise of judgment as based upon other knowledge than that shown in the mere figures.

That the atomic weight of cobalt is higher than that of nickel clearly appears from the evidence. Nevertheless, attempts have been made to prove the opposite. For example, Parker and Sexton[1] assert that in fifteen electrolytic comparisons of silver and cobalt, they have obtained a mean value of Co = 57.7, which is lower than the atomic weight of nickel. Barkla and Sadler,[2] in studying the permeability of metals to the secondary Röntgen rays, have found that property to be a periodic function of the atomic weights. By interpolation in the periodic curve so obtained they find values for Ni ranging between 61.2 and 61.6, whereas the currently accepted atomic weight appears to be anomalous, at least as regards the physical property now under consideration. These conclusions, however, cannot weigh very heavily as against the clear chemical evidence. As for Parker and Sexton's work, the authors give no details which would furnish an adequate basis for discussion.

RUTHENIUM.

The atomic weight of this metal has been determined by Claus, by Joly, and by Vogt. Although Claus[3] employed several methods, we need only consider his analyses of potassium rutheniochloride, K_2RuCl_5. The salt was dried by heating to 200° in chlorine gas, but even then retained a trace of water. The percentage results of the analyses are as follows:

Ru.	*2KCl.*	*3Cl.*
28.96	40.80	30.24
28.48	41.39	30.22
28.91	41.08	30.04
Mean, 28.78	41.09	30.17

Reckoning directly from the percentages, we get the following discordant values for Ru:

From percentage of metal	Ru=103.21
From percentage of 2KCl	" =104.44
From percentage of 3Cl	" =101.48

These results are obviously of little importance, especially since two of them are not in accord with the position of ruthenium in the periodic system. The work of Joly is more satisfactory.[4] Several compounds of ruthenium were analyzed by reduction in a stream of hydrogen with the following results:

First, reduction of RuO_2:

RuO_2.	*Ru*	*Per cent Ru.*
2.1387	1.6267	76.060
2.5846	1.9658	76.058
2.3682	1.8016	76.075
2.8849	2.1939	76.046
		Mean, 76.060±.0040

Hence, Ru = 101.67.

[1] Nature, 76, 316. 1907. [2] Phil. Mag. (6), 14, 408. 1907. [3] Journ. prakt. Chem., 34, 435. 1845. [4] Compt. Rend., 108, 946.

Second, reduction of the salt $RuCl_3.NO.H_2O$:

Per cent Ru.
39. 78
39. 66
Mean, 39. 72±. 0405

Third, reduction of $RuCl_3.NO.2NH_4Cl$:

Per cent Ru.
29. 44
29. 47
Mean, 29. 455±. 0101

The analyses of ruthenium dioxide by Vogt [1] were by reduction of the compound in hydrogen. The data obtained with vacuum weights are as follows:

RuO_2.	*Ru.*	*Per cent Ru.*
1. 11748	0. 84998	76. 062
. 39454	. 30009	76. 060
. 67499	. 51315	76. 023
. 74681	. 56800	76. 056
. 57902	. 44043	76. 064
. 40827	. 31049	76. 050
		Mean, 76. 0525±. 0042

Hence, Ru = 101.62.

Vogt rejects the third of these analyses, which varies widely from the others, and finds Ru = 101.66 in close agreement with Joly's determination. The two series, Vogt's and Joly's combined give a mean percentage of 76.0565 ± .0029.

There are now three ratios available from which to compute the atomic weight of ruthenium. Reducing them with Cl = 35.4605 ± .00011, N = 14.0081, ± .00008, and H = 1.0078 ± .00001, we have—

From $RuCl_3.NO.2NH_4Cl$	Ru = 101. 625±. 0378
From RuO_2	101. 648±. 0129
From $RuCl_3.NO.H_2O$	101. 742±. 1242
General mean,	Ru = 101. 649±. 0121

This value appears to be a fair approximation to the truth, but more determinations by other methods are desirable.

RHODIUM.

Berzelius [2] determined the atomic weight of this rhodium by the analysis of sodium and potassium rhodiochlorides, Na_3RhCl_6 and K_2RhCl_5. The latter salt was dried by heating in chlorine. The compounds were analyzed by reduction in hydrogen after the usual manner. Reduced to percentages, the analyses are as follows:

In Na_3RhCl_6.

Rh.	*3NaCl.*	*3Cl.*
26. 959	45. 853	27. 189
27. 229	45. 301	27. 470
.....	.....	27. 616
Mean, 27. 094	Mean, 45. 577	Mean, 27. 425

In K_2RhCl_5.

Rh.	*2KCl.*	*3Cl.*
28. 989	41. 450	29. 561

[1] Situngsb. phys. med. Soz. Erlangen, 43, 268. 1912.

[2] Poggend. Annalen, 13, 435. 1828.

From analyses of the sodium salt we get the following values for Rh:

From per cent of metal	Rh=104.72
From per cent of NaCl	" =103.05
From per cent of 3Cl	" =106.13
From ratio between 3Cl and Rh	" =105.10
From ratio between 3NaCl and Rh	" =104.27

These are discordant figures; but the last one fits in fairly well with the values calculated from the potassium compound, which are as follows:

From per cent of metal	Rh=104.30
From per cent of KCl	" =104.30
From per cent of Cl	" =104.37
From Rh : 3Cl ratio	" =104.32
From Rh : 2KCl ratio	" =104.31
Mean	Rh=104.37

The determinations by Jörgensen [1] seem to have been preliminary, but are good so far as they go. Rhodium pentamine chloride, $Rh(NH_3)_5Cl_3$, was ignited in hydrogen, and the residual metal was cooled in an atmosphere of carbon dioxide. The data are as follows:

Chloride.	*Rhodium.*	*Per cent Rh.*
3.5180	1.2310	34.991
2.1507	.7517	34.951
.9091	.3182	35.002
1.9889	.6960	34.994
		Mean, 34.984±.0076

Hence, Rh=103.06.

In a single analysis of the corresponding bromide, 1.2736 grammes gave 0.3065 of rhodium, or 24.065 per cent. Hence, Rh=102.97. In another experiment 1.2675 grammes of bromide gave 1.6683 of AgBr. Hence, Rh=103.12.

Seubert and Kobbe [2] determined the atomic weight in the same way, that is, by igniting rhodium pentamine chloride in hydrogen and weighing the residual metal. Their results are given below:

Chloride.	*Rh.*	*Per cent Rh.*
1.8585	0.6496	34.953
1.5560	.5435	34.929
1.5202	.5310	34.930
2.0111	.7031	34.961
1.8674	.6528	34.958
2.4347	.8513	34.965
2.3849	.8338	34.962
2.5393	.8881	34.974
1.4080	.4920	34.943
1.4654	.5123	34.960
		Mean, 34.954±.0032

Hence, Rh=102.92.

In the sixth experiment the ammonium chloride formed was collected in a bulb tube and estimated by weighing as silver chloride; 3.5531 grammes of AgCl were obtained. Hence, Rh=103.12.

The same process was followed by Hüttlinger,[3] who obtained almost exactly the same result. His figures are as follows:

Chloride.	*Rh.*	*Per cent Rh.*
1.60574	0.56124	34.951
1.67310	.58492	34.960
1.30182	.45507	34.956
		Mean, 34.956±.0020

Hence, Rh=102.94.

[1] Journ. prakt. Chem. (2), 27, 486. 1883. [2] Liebig's Annalen, 260, 318. 1890. [3] Sitzungsb. phys. med. Soz. Erlangen, 39, 1. 1907.

Another series, somewhat later, by H. Dittmar,[1] gave the subjoined figures with vacuum weights:

Chloride.	*Rh.*	*Per cent Rh.*
2.01526	0.70465	34.967
1.83589	.64173	34.954
1.57210	.54934	34.943
2.17528	.76046	34.959
2.03911	.71271	34.952
2.20000	.76890	34.950
1.02840	.35941	34.948
		Mean, 34.953±.0020

Hence, Rh = 102.94.

The four series of analyses of the chloride combine as follows:

Jörgensen	34.984±.0076
Seubert and Kobbe	34.954±.0032
Hüttlinger	34.956±.0020
Dittmar	34.953±.0020
General mean	34.955±.0013

The work of Hüttlinger and Dittmar was done in the laboratory at Erlangen, under the direction of Gutbier. So, too, was that of Renz,[2] who made similar analyses of rhodium pentamine bromide, $Rh(NH_3)_5Br_3$. His data, with vacuum weights, are as follows:

Bromide.	*Rh.*	*Per cent Rh.*
0.87624	0.21057	24.031
1.56500	.37638	24.049
2.04033	.49069	24.049
2.00120	.48135	24.053
1.89278	.45525	24.051
2.30210	.55416	24.071
1.02065	.24555	24 058
1.31485	.31622	24.049
1.86060	.44766	24.059
1.51040	.36339	24.059
		Mean, 24.053±.0022

Hence, Rh = 102.907.

Ignoring the early work of Berzelius, and the single analysis by Jörgensen of rhodium pentamine bromide, we have two ratios from which to compute the atomic weight of rhodium:

(1) $Rh(NH_3)_5Cl_3 : Rh :: 100 : 34.955 \pm .0013$
(2) $Rh(NH_3)_5Br_3 : Rh :: 100 : 24.053 \pm .0022$

To reduce these we have—

Cl = 35.4605±.00011 N = 14.0081±.00008
Br = 79.9228±.00015 H = 1.0078±.00001

Hence,

From ratio—

2	Rh = 102.907 ±.0099
1	102.9325±.0044
General mean	Rh = 102.928 ±.0040

PALLADIUM.

The first work upon the atomic weight of palladium seems to have been done by Berzelius. In an early paper [3] he states that 100 parts of the metal united with 28.15 of sulphur. Hence Pd = 113.91, a result which is clearly of no present value.

In a later paper [4] Berzelius published two analyses of potassium palladiochloride, K_2PdCl_4. The salt was decomposed by ignition in hydrogen, as was the case with the double chlorides of

[1] Sitzungsb. phys. med. Soz. Erlangen, 40, 184. 1909.
[2] Inaug. Diss., Erlangen, 1909.
[3] Poggend, Annalen, 8, 177. 1826.
[4] Poggend. Annalen, 13, 454. 1828.

potassium with platinum, osmium, and iridium. Reducing his results to percentages, we get the following composition for the substance in question:

Pd.	*2KCl.*	*Cl_2.*
32.726	46.044	21.229
32.655	45.741	21.604
Mean, 32.690	Mean, 45.892	Mean, 21.416

From these percentages, calculating directly, very discordant results are obtained:

From percentage of metal	Pd=106.86
From percentage of KCl	Pd=104.90
From percentage of Cl_2 (loss)	Pd=111.11

Obviously the only way to get satisfactory figures is to calculate from the ratio between the Pd and 2KCl, eliminating thus the influence of water in the salt. The two experiments give, as proportional to 100 parts of KCl, the following of Pd:

71.075
71.391
Mean, 71.233±.1066

Hence, Pd = 106.22.

In 1847 Quintus Icilius [1] published a determination, which need be given only for the sake of completeness. He ignited potassium palladiochloride in hydrogen, and found the following amounts of residue. His weights are here recalculated into percentages:

64.708
64.965
64.781
Mean, 64.818

From this mean, Pd = 112.05. This result has no present value.

In 1899 Keiser's first determinations of this constant appeared.[2] Finding the potassium palladiochloride to contain "water of decrepitation," he abandoned its use and resorted to palladiammonium chloride, $Pd(NH_3Cl)_2$, as the most available compound for his purpose. This salt, heated in hydrogen, yields spongy palladium, which was allowed to cool in a current of dry air, in order to avoid gaseous occlusions. The salt itself was dried, previous to analysis, first over sulphuric acid, and then in an air bath at a temperature from 120° to 130°. Two series of experiments were made, the second series starting out from palladium produced by the first series. The data are as follows:

First Series.

$Pd(NH_3Cl)_2$.	*Pd.*	*Per cent Pd.*
0.83260	0.41965	50.402
1.72635	.86992	50.391
1.40280	.70670	50.378
1.57940	.79562	50.375
1.89895	.95650	50.370
1.48065	.74570	50.363
1.56015	.78585	50.370
1.82658	.92003	50.369
2.40125	1.20970	50.378
1.10400	.55629	50.389
.93310	.47010	50.380
		Mean, 50.379±.0008

Reduced to a vacuum this becomes 50.360.
Hence, Pd = 106.51.

[1] "Die Atomgewichte vom Pd, K, Cl, Ag, C, und H, nach der Methode der kleinsten Quadrate berechnet." Inaug. Diss. Göttingen, 1847. Contains no other original analyses.

[2] Amer. Chem. Journ., 11, 398. 1889.

Second Series.

$Pd(NH_3Cl)_2$.	*Pd.*	*Per cent Pd.*
2.61841	1.31900	50.374
2.23420	1.12561	50.381
1.73553	.87445	50.385
1.69160	.85210	50.372
1.72403	.86825	50.362
1.12222	.56535	50.378
1.17457	.59200	50.401
2.42760	1.22280	50.371
		Mean, 50.378±.0028
		Reduced to vacuum, 50.359

Hence, Pd = 106.50.

The reductions to a vacuum are neglected by Keiser himself, but are here added in order to secure uniformity with later results by the same author.

Bailey and Lamb [1] made experiments upon several compounds of palladium, but finally settled upon palladiammonium chloride, like Keiser. Two preliminary experiments, however, with potassium palladiochloride are given, in which the salt was reduced in hydrogen, and both Pd and KCl were weighed. The data are as follows, with the ratio (calculated as with Berzelius's experiments) given in a third column:

2KCl.	*Pd.*	*Ratio.*
1.49767	1.05627	70.528
.90484	.63738	70.441
		Mean, 70.485±.0290

Hence, Pd = 105.11.

The palladiammonium chloride was studied by two methods. First, weighed quantities of the salt were reduced in hydrogen, the ammonium chloride so formed was collected in an absorption apparatus, and then precipitated with silver nitrate. The weights found were as follows, with the $Pd(NH_3Cl_2)$ proportional to 100 parts of silver chloride given in the third column:

$Pd(NH_3Cl)_2$.	*AgCl.*	*Ratio.*
1.24276	1.682249	73.879
1.08722	1.468448	74.040
1.47666	2.000164	73.828
1.34887	1.837957	73.390
1.74569	2.362320	73.898
		Mean, 73.807±.0742

Hence, Pd = 106.61. Bailey and Lamb regard this as too high, and suspect loss of NH_4Cl during the operation.

The second series of data resemble Keiser's. The salt was reduced in hydrogen, and the spongy palladium was weighed in a Sprengel vacuum. The data are as follows:

	$Pd(NH_3Cl)_2$.	*Pd.*	*Per cent Pd.*
A	1.890597	0.947995	50.143
	1.874175	.940271	50.170
B	1.307076	.654687	50.088
	1.340045	.633207	50.238
	1.905536	.955950	50.167
	1.685582	.846472	50.218
C	1.691028	.849120	50.213
	2.112530	1.059690	50.162
	2.110653	1.057910	50.122
	1.969100	.988155	50.184
			Mean, 50.171±.0099

Hence, Pd = 105.71. Bailey and Lamb's weighings are all reduced to a vacuum.

Keller and Smith,[2] reviewing Keiser's work, find that palladiammonium chloride, prepared as Keiser prepared it, may retain traces of foreign metals, and especially of copper. Accordingly,

[1] Journ. Chem. Soc., 61, 745. 1892.

[2] Amer. Chem. Journ., 14, 423. 1892.

they prepared a quantity of the salt, after a thorough and elaborate process of purification, dried it with extreme care, and then determined the palladium by electrolysis in silver-coated platinum dishes. The precipitated palladium was dried under varying conditions, concerning which the original memoir must be consulted, and was proved to be free from occluded hydrogen. By this method two sets of experiments were made to determine the atomic weight of palladium; but for present purposes the two may fairly be treated as one. The data obtained are as follows, but the weights do not appear to have been reduced to a vacuum:

	$Pd(NH_3Cl)_2$.	*Pd.*	*Per cent Pd.*
A	1.29960	0.65630	50.504
A	1.05430	.53253	50.510
A	1.92945	.97455	50.509
	1.94722	.98343	50.504
B	1.08649	.54870	50.502
B	1.28423	.64858	50.503
B	1.68275	.85010	50.519
B	1.69113	.85431	50.517
B	1.80805	.91310	50.502
			Mean, 50.508±.0014

Hence, Pd = 107.14, a result notably hlgher than Keiser's.

Keller and Smith account for the difference between their determinations and Keiser's partly by the assumption that the materials used by the latter were not pure, and partly by considerations based on the process. In order to clarify the latter part of the question they made three sets of experiments by Keiser's method, slightly varying the conditions. First, the chloride was not pulverized before ignition, and slight decrepitation took place, while dark stains of palladium appeared in the reduction tube, indicating loss by volatilization. Secondly the chloride was prepared from crude palladium exactly as described by Keiser, but was pulverized before reduction. No decrepitation ensued, but traces of palladium were volatilized. The third series, also on finely pulverized material, was like the second; but the palladiammonium chloride was purified by Keller and Smith's process. The three series, here treated as one, are as follows:

	$Pd(NH_3Cl)_2$.	*Pd.*	*Per cent Pd.*
First series....	.62955	0.31743	50.422
First series....	.77270	.38942	50.397
First series....	.83252	.41918	50.350
First series....	.99055	.49895	50.371
Second series..	1.02175	.51468	50.372
Second series..	1.10325	.55590	50.388
Second series..	.66690	.33590	50.367
Second series..	.86840	.43733	50.360
Second series..	1.41430	.71255	50.382
Second series..	1.15234	.58050	50.376
Third series...	.96229	.48502	50.403
Third series...	.97804	.49294	50.401
Third series...	.94253	.47517	50.414
Third series...	.86090	.43405	50.430
			Mean, 50.388±.0043

Hence, Pd = 106.63.

The three series seem to be fairly in agreement between themselves, and with Keiser's work, but diverge seriously from the electrolytic data.

Keller and Smith also attempted to determine the atomic weight of palladium by heating the palladiammonium chloride in sulphuretted hydrogen, and so converting it into the sulphide, PdS. These data were obtained:

$Pd(NH_3Cl)_2$.	*PdS.*	*Per cent PdS.*
0.71699	0.47066	65.644
1.31688	.86445	65.659
		Mean, 65.651±.0051

Hence, Pd = 107.15. This result, however, is affected by the work of Petrenko-Kritschenko,[1] who has shown the existence of the sulphide PdS to be uncertain.

Joly and Leidié,[2] in their determinations of this atomic weight, returned to the potassium palladiochloride, K_2PdCl_4. In their first series of experiments the salt was dried in vacuo at ordinary temperatures. It was then electrolyzed in a solution acidulated with hydrochloric acid, both the deposited palladium and the potassium chloride being weighed. The palladium was dried, ignited in a stream of hydrogen and cooled in an atmosphere of carbon dioxide. The results were as follows, with the column added giving the Pd equivalent to 100 parts of KCl:

K_2PdCl_4.	Pd.	2KCl.	Ratio.
1.0255	0.3919	0.5520	70.996
1.2178	.3937	.5551	70.924
1.2518	.4048	.5687	71.016
			Mean, 70.979±.0188

Hence Pd = 105.84.

This series was rejected by the authors, because the salt was found to contain water—in one oase 0.23 per cent. This error, however, should not invalidate the Pd : KCl ratio. In a second series the palladiochloride was dried in vacuo at 100°, giving the following data:

K_2PdCl_4.	Pd.	2KCl.	Ratio.
1.3635	0.4422	0.6186	71.484
3.0628	.9944	1.3929	71.391
1.4845	.4816	.6782	71.011
1.7995	.5838	.8206	71.143
			Mean, 71.257±.0736

These experiments seem to be less concordant than the preceding set. It must be noted, however, that the authors reject the KCl determinations and compute directly from the ratio between the salt and the metal. But the ratio here chosen agrees best with the determinations made by other observers, giving for this series the mean value Pd = 106.26, and is, moreover, uniform with the data given by Berzelius and by Bailey and Lamb.

Joly and Leidiè also give two experiments made by reducing the K_2PdCl_4 in hydrogen, with the subjoined results:

K_2PdCl_4.	Pd.	2KCl.	Ratio.
2.4481	0.7949	1.1168	71.177
1.8250	.5930	.8360	70.933
			Mean, 71.055±.0823

Hence Pd = 105.96.

Combining these data with previous series, we have—

Berzelius	71.233±.1066
Bailey and Lamb	70.485±.0290
Joly and Leidié, first	70.979±.0188
Joly and Leidié, second	71.257±.0736
Joly and Leidié, third	71.055±.0823
General mean	70.865±.0150

In view of the discordance among the determinations hitherto cited and because of the criticisms made by Keller and Smith, Keiser, jointly with Miss Mary B. Breed,[3] repeated his former work, with some variations, and new precautions to insure accuracy. His general method was the same as before, namely, the reduction of palladiammonium chloride by a stream of hydrogen. First, palladium was purified by distillation as $PdCl_2$ at low red heat in a current of chlorine. From this chloride the palladiammonium salt was then prepared. Upon heating the compound gently in a stream of hydrogen, decomposition ensued absolutely without decrepitation or loss of palladium by volatilization. Neither source of error existed. The results obtained were these:

[1] Zeit. anorg. Chem., 4, 251. 1893. [2] Compt. Rend., 116, 147. 1893. [3] Amer. Chem. Journ., 16, 20. 1894.

$Pd(NH_3Cl)_2$.	*Pd.*	*Per cent Pd.*
1. 60842	0. 80997	50. 358
2. 08295	1. 04920	50. 371
2. 02440	1. 01975	50. 373
2. 54810	1. 28360	50. 375
1. 75505	. 88410	50. 375
		Mean, 50. 370±. 0023
		Reduced to a vacuum, 50. 351

Hence Pd = 106.46.

In a second series of experiments, palladium was purified as in the earlier investigation, but with special care to eliminate rhodium, iron, copper, gold, mercury, etc. The palladiammonium salt prepared from this material gave as follows:

$Pd(NH_3Cl)_2$.	*Pd.*	*Per cent Pd.*
1. 50275	0. 75685	50. 364
1. 23672	. 62286	50. 365
1. 34470	. 67739	50. 375
1. 49059	. 75095	50. 379
		Mean, 50. 371±. 0026
		Reduced to a vacuum, 50. 352

Hence Pd = 106.47.

Here, again, no loss from decrepitation or volatilization occurred, although evidence of such loss was carefully sought for.

Hardin,[1] in 1899, made three series of determinations of the atomic weight of palladium, by reduction of three palladium salts in hydrogen. His results, with weights reduced to a vacuum, are as follows:

First: Reduction of diphenyl-pallad-diammonium chloride,

$Pd(C_6H_5.NH_2Cl)_2$:

Salt.	*Pd.*	*Per cent Pd.*
0. 98480	0. 28953	29. 400
1. 10000	. 32310	29. 376
1. 02820	. 30210	29. 381
1. 19230	. 35040	29. 389
1. 40550	. 41300	29. 385
1. 26000	. 37040	29. 397
1. 25510	. 66310	29. 404
		Mean, 29. 390±. 0029

Hence Pd = 107.00.

Second: Reduction of diphenyl-pallad-diammonium bromide,

$Pd(C_6H_5.NH_2Br)_2$:

Salt.	*Pd.*	*Per cent Pd.*
0. 88567	0. 20917	23. 617
1. 31280	. 31000	23. 614
1. 50465	. 35540	23. 620
2. 01635	. 47635	23. 624
2. 92300	. 69080	23. 633
		Mean, 23. 622±. 0023

Hence Pd = 107.01.

Third: Reduction of palladium ammonium bromide, $(NH_4)_2PdBr_4$:

Salt.	*Pd.*	*Per cent Pd.*
0. 77886	0. 18006	23. 118
1. 53109	. 35881	23. 108
2. 75168	. 63614	23. 118
1. 88136	. 43478	23. 110
		Mean, 23. 1135±. 0018

Hence Pd = 106.95.

[1] Journ. Amer. Chem. Soc., 21, 947.

These determinations are notably higher than those made by other methods. After reduction, the palladium was heated to redness for two hours in a stream of dry air, to remove possible carbon. It was then heated again in hydrogen, and finally cooled in a current of air. Hydrogen could hardly have been occluded in the final product.

Amberg,[5] whose determinations appeared in 1905, resorted to palladiammonium chloride as his initial substance. Three series of analyses were made, with scrupulously purified material, and all weights were reduced to a vacuum. First, the salt was reduced electrolytically. The precipitated palladium was weighed, and in the rinsings from it the chlorine was determined as silver chloride. The data are subjoined, with the ratio $2AgCl : Pd(NH_3Cl)_2 :: 100 : x$ in the fifth column:

Salt.	*Pd.*	*AgCl.*	*Per cent Pd.*	*AgCl ratio.*
1.06045	0.53609	.....	50.553	.....
1.00028	.50528	1.35867	50.493	73.622
1.66386	.84085	2.25437	50.541	73.807
.83195	.42092	1.12282	50.594	74.095
1.91591	.96886	2.59799	50.569	73.746
			Mean, 50.550	Mean, 73.818
			±.0110	±.0677

From the percentage of metal, Pd = 107.32.

From the AgCl ratio, Pd = 106.64.

Amberg's secondseries of analyses resembles the first, except that the palladium was precipitated by hydrazin sulphate. The percentage of metal is given by Amberg, but not the weights actually obtained:

Salt.	*AgCl.*	*Per cent Pd.*	*AgCl ratio.*
1.32493	1.78656	50.12	74.171
1.02642	1.39247	50.29	73.712
1.30335	1.76875	50.36	73.518
1.59709	2.16641	.....	73.721
1.88622	2.55028	50.49	73.961
2.59665	3.51783	50.68	73.812
		Mean, 50.388	Mean, 73.814
		±.2064	±.0614

From percentage of metal, Pd = 106.63.

From AgCl ratio, Pd = 106.63.

The silver chloride ratio combines with previous determinations as follows:

Bailey and Lamb	73.807±.0742
Amberg, first series	73.818±.0677
Amberg, second series	73.814±.0614
General mean	73.813±.0388

In his third series of analyses Amberg determined only the palladium, which was precipitated electrolytically from a sulphuric acid solution of the palladiammonium chloride, with a rapidly rotating anode. This series is excellent, but the preceding series of palladium determinations are negligible:

Salt.	*Pd.*	*Per cent Pd.*
0.62446	0.31470	50.396
.83878	.42280	50.407
1.50282	.75725	50.389
1.06704	.53763	50.385
1.98342	.99971	50.403
1.53093	.77153	50.396
1.18995	.59971	50.398
.62635	.31572	50.406
1.76110	.88739	50.388
3.79639	1.91298	50.389
3.97553	2.00333	50.392
4.62100	2.32834	50.386
		Mean, 50.395±.0015

Hence, Pd = 106.66.

[1] Liebig's Annalen, 341, 255.

The atomic weight determinations by Krell, Woernle, and Haas were all made in the laboratory of Professor Gutbier at Erlangen. Krell [1] reduced palladiammonium (palladosamine) chloride in hydrogen, and afterwards heated the reduced metal in a stream of carbon dioxide. His figures, with vacuum weights, are subjoined:

Salt.	*Pd.*	*Per cent Pd.*
1.83034	0.92197	50.372
1.73474	.87433	50.401
1.92532	.96524	50.396
2.63544	1.32868	50.416
3.23840	1.63175	50.387
		Mean, 50.3945±.0050

Hence, Pd = 106.65. The first, aberrant determination in the series, is rejected by Krell.

Woernle [2] also made analyses of palladiammonium chloride. The first two reductions were effected in hydrogen, the other determinations were electrolytic. His figures, with vacuum weights, are as follows:

Salt.	*Pd.*	*Per cent Pd.*
2.94682	1.48493	50.391
1.83140	.92296	50.396
1.02683	.51479	50.397
1.22435	.61708	50.401
1.46735	.73944	50.393
.59796	.30139	50.403
2.64584	1.33329	50.392
		Mean, 50.396±.0012

Hence, Pd = 106.66.

Haas [3] analyzed palladiammonium bromide, $Pd(NH_3Br)_2$, by reduction in hydrogen. The reduced metal was subsequently heated in carbon dioxide. His data, with vacuum weights, are as follows:

Bromide.	*Pd.*	*Per cent Pd.*
2.06470	0.73274	35.488
1.73455	.61563	35.492
2.64773	.93978	35.493
1.29106	.45821	35.491
2.26758	.80490	35.495
1.90770	.67704	35.489
1.77729	.63082	35.493
		Mean, 35.492±.0006

Hence, Pd = 106.69.

Kemmerer [4] analyzed two palladiammonium compounds, the chloride and the cyanide, both by reduction in hydrogen, with subsequent cooling of the reduced metal in an atmosphere of nitrogen. Vacuum weights are given throughout. With the chloride, two sets of determinations were made, on two distinct preparations, but both series are here treated as one. The data are subjoined:

	Chloride.	*Pd.*	*Per cent Pd.*
A	.89187	0.44885	50.327
A	.77931	.39218	50.324
A	.66980	.33711	50.330
A	1.08373	.54541	50.327
A	.96048	.48338	50.327
B	.95615	.48129	50.336
B	.94087	.47356	50.332
B	.90106	.45353	50.333
B	1.16994	.58908	50.351
			Mean, 50.332±.0018

Hence, Pd = 106.39.

[1] Inaugural Dissertation, Erlangen, 1906.
[2] Sitzungsb. phys. med. Soz., Erlangen, 38, 278. 1907.
[3] Inaug. Dissertation, Erlangen, 1908.
[4] Thesis, University of Pennsylvania, 1908.

With the cyanide, Pd $(NH_3CN)_2$, Kemmerer obtained the following results:

Cyanide.	*Pd.*	*Per cent Pd.*
0.85860	0.47463	55.280
1.19378	.66002	55.288
1.41818	.78408	55.288
1.05254	.58206	55.301
1.39510	.77153	55.303
1.66196	.91881	55.285
		Mean, 55.291±.0025

Hence, Pd = 106.46.

Like Haas, Gebhardt [1] also made analyses of palladiammonium bromide, and by the same method. His figures, with vacuum weights, are as follows:

Bromide.	*Pd.*	*Per cent Pd.*
3.32462	1.17984	35.488
2.68383	.95245	35.488
1.40117	.49731	35.492
2.61673	.92877	35.494
2.64229	.93787	35.495
2.54424	.90293	35.489
2.00456	.71143	35.491
		Mean, 35.491±.0007

Hence, Pd = 106.68.

The work of Haas and Gebhardt was done under the direction of Gutbier, who has combined their material in a memoir bearing their names in joint authorship with his.[2] In this memoir 10 additional analyses of the bromide are given, but 6 of them are rejected by Gutbier as unsatisfactory. I prefer, however, to include them in this discussion, but with low weight. The 10 determinations I have divided into two sets, one containing the 4 preferred analyses, the other the 6 questionable ones. Their unequal value appears in the probable errors:

Bromide.	*Pd.*	*Per cent Pd.*
3.09278	1.09783	35.496
1.98039	.70288	35.491
1.50032	.53253	35.494
2.84500	1.00992	35.498
		Mean, 35.495±.0011

Hence, Pd = 106.70.

Bromide.	*Pd.*	*Per cent Pd.*
0.54402	0.19286	35.450
.80237	.28468	35.479
.91601	.32509	35.489
.42942	.15288	35.461
.76884	.27271	35.470
.62795	.22270	35.464
		Mean, 35.469±.0038

Hence, Pd = 106.58.

The four series of analyses of the bromide now combine thus:

Haas	35.492±.0006
Gebhardt	35.491±.0007
Gutbier, Haas, and Gebbardt	35.495±.0011
Gutbier, Haas, and Gebhardt	35.469±.0038
General mean	35.491±.00042

The influence of the determinations rejected by Gutbier is insignificant.

One more series of analyses of palladiammonium chloride is due to Shinn.[3] The salt was dissolved in water, and from the solution the metal was precipitated by ammonium formate. The data, with vacuum weights, are as follows:

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[1] Sitz. phys.-med. Soz., Erlangen, 40, 65. 1909.

[2] Gutbier, Haas, and Gebhardt, Journ. prakt. Chem. (2), 79, 457. 1909.

[3] Journ. Amer. Chem. Soc., 34, 1448. 1912.

Chloride.	*Pd.*	*Per cent Pd.*
1.03021	0.51923	50.400
1.45506	.73323	50.392
1.10384	.55645	50.410
.88141	.44448	50.428
1.53091	.77160	50.401
1.98887	1.00212	50.386
1.45102	.73174	50.429
1.57909	.79563	50.385
1.61705	.81583	50.452
		Mean, 50.409±.0040

Hence, Pd=106.704.

The 14 series of determinations of the percentage of palladium in palladiammonium chloride now combine as follows:

Keiser, first series	50.360 ±.0008
Keiser, second series	50.359 ±.0028
Bailey and Lamb	50.171 ±.0099
Keller and Smith, electrolytic	50.508 ±.0014
Keller and Smith, hydrogen series	50.388 ±.0043
Keiser and Breed, first series	50.351 ±.0023
Keiser and Breed, second series	50.352 ±.0026
Amberg, first series	50.550 ±.0110
Amberg, second series	50.388 ±.2064
Amberg, third series	50.395 ±.0015
Krell	50.3945±.0050
Woernle	50.396 ±.0012
Kemmerer	50.332 ±.0025
Shinn	50.409 ±.0040
General mean	50.3885±.0005

Nine ratios are now available from which to compute the atomic weight of palladium, as follows:

(1) $2KCl : Pd :: 100 : 70.865 \pm .0150$
(2) $2AgCl : Pd\,(NH_3Cl)_2 :: 100 : 73.813 \pm .0388$
(3) $Pd\,(NH_3Cl)_2 : Pd :: 100 : 50.3885 \pm .0005$
(4) $Pd\,(NH_3Br)_2 : Pd :: 100 : 35.491 \pm .00042$
(5) $Pd\,(NH_3CN)_2 : Pd :: 100 : 55.291 \pm .0025$
(6) $Pd\,(C_6H_5.NH_2Cl)_2 : Pd :: 100 : 29.390 \pm .0029$
(7) $Pd\,(C_6H_5 : NH_2Br)_2 : Pd :: 100 : 23.622 \pm .0023$
(8) $(NH_4)_2PdBr_4 : Pd :: 100 : 23.1135 \pm .0018$
(9) $Pd\,(NH_3Cl)_2 : PdS :: 100 : 65.651 \pm .0051$

To reduce these ratios we have—

Ag=107.880±.00016	C=12.0025±.00019
Cl=35.4605±.00011	N=14.0081±.00008
Br=79.9228±.00015	S=32.0650±.00012
K=39.0975±.00011	H= 1.0078±.00001

Hence,

From ratio—	
1	Pd=105.671±.0224
4	106.465±.0077
2	106.624±.1112
3	106.628±.0015
4	106.683±.0015
8	106.951±.0087
6	107.003±.0115
7	107.010±.0109
9	107.149±.0490
General mean	Pd=106.659±.0010

The international value, Pd=106.7, is probably not far from the truth, but may be a trifle too high. Ratio 4 is in good agreement with it.

OSMIUM.

The atomic weight of this metal has been determined by Berzelius, by Fremy, by Seubert, and by Seybold.

Berzelius [1] analyzed potassium osmichloride, igniting it in hydrogen like the corresponding platinum salt. 1.3165 grammes lost 0.3805 of chlorine, and the residue consisted of 0.401 gramme potassium chloride, with 0.535 gramme of osmium. Calculating only from the ratio between the Os and the KCl, the data give Os = 198.94.

Fremy's determination [2] is based upon the composition of osmium tetroxide. No details as to weighings or methods are given; barely the final result is stated, namely, Os = 199.65.

When the periodic law came into general acceptance, it became clearly evident that both of the foregoing values for osmium must be several units too high. A redetermination was therefore undertaken by Seubert,[3] who adopted methods based upon that of Berzelius. First, ammonium osmichloride was reduced by heating in a stream of hydrogen. The residual osmium was weighed, and the ammonium chloride and hydrochloric acid given off were collected in a suitable apparatus, so that the total chlorine could be estimated as silver chloride. The weights were as follows:

Am_2OsCl_6.	*Os.*	*6AgCl.*
1.8403	0.7996	3.5897
2.0764	.9029	4.0460
2.1501	.9344	4.1950
2.1345	.9275	4.1614

Hence we have for the percentage of osmium and for the osmichloride proportional to 100 parts of AgCl—

Per cent Os.	*AgCl : Salt.*
43.446	51.266
43.484	51.320
43.458	51.254
43.453	51.293
	Mean, 51.283 ± .0099

In a later paper [4] two more reductions are given, in which only osmium was estimated:

Salt.	*Os.*	*Per cent Os.*
2.6687	1.1597	43.456
2.6937	1.1706	43.457

These determinations, included with the previous four as one series, give a mean percentage of Os in Am_2OsCl_6 of 43.459 ± .0036.

Secondly, potassium osmichloride was treated in the same way, but the residue weighed consisted of Os + 2KCl. From this the potassium chloride was dissolved out, recovered by evaporating the solution, and weighed separately. The volatile portion, 4HCl, was also determined by precipitation as silver chloride. In Seubert's first paper these data are given:

K_2OsCl_6.	*Os.*	*2KCl.*	*4AgCl.*
2.5148	.....	0.7796	2.9837
2.1138	0.8405	.6547	2.5076

Hence, with salt proportional to 100 parts of AgCl in the last column, we have—

Per cent Os.	*Per cent KCl.*	*AgCl : Salt.*
.....	31.000	84.091
39.762	30.973	84.102
		Mean, 84.097 ± .0030

In his second paper Seubert gives fuller data relative to the potassium osmichloride, but treats it somewhat differently. The salt was reduced by a stream of hydrogen as before, but

[1] Poggend. Annalen, 13, 530. 1828.
[2] Compt. Rend., 19, 468. Journ. prakt. Chem. 31, 410. 1844.
[3] Ber. Deutsch. chem. Ges., 21. 1839. 1888.
[4] Liebig's Annalen, 261, 258.

after that the boat containing the Os+2KCl was transferred to a platinum tube, in which, by prolonged heating in the gas, the potassium chloride was completely volatilized. The determinations of 4Cl as 4AgCl were omitted. Two series of data are given, as follows:

K_2OsCl_6.	*Os.*	*Per cent Os.*
1.1863	0.4691	39.543
.9279	.3667	39.519
1.0946	.4330	39.558
1.6055	.6351	39.558
.4495	.1778	39.555
.8646	.3417	39.521
.7024	.2781	38.593
1.2742	.5041	39.562
1.0466	.4141	39.566
		Mean, 39.553±.0052

K_2OsCl_6.	*2KCl.*	*Per cent KCl.*
2.2032	0.6820	30.955
2.0394	.6312	30.950
2.7596	.8544	30.961
2.4934	.7710	30.922
2.8606	.8843	30.913
2.8668	.5768	30.898
1.2227	.3778	30.899
		Mean, 30.931
		Earlier set {31.000 / 30.973
		Mean of all nine determinations, 30.941±.0079

The single percentage of osmium given in Seubert's first paper is negligible.

The analyses of ammonium osmichloride by Seybold [1] are of slight importance because they are not concordant. The data are as follows. They fall into two groups:

Group 1.

Am_2OsCl_6.	*Os.*	*Per cent Os.*
0.92831	0.40110	43.209
1.37982	.59629	43.215
.86661	.37448	43.212
1.17170	.50642	43.221
1.31312	.56730	43.203
		43.212

Group 2.

4.94681	2.14915	43.447
3.78304	1.64378	43.452
1.44792	.62958	43.412
		43.437

Seybold regards the high values given in the second group as due to the probable absorption of oxygen by the osmium. It is equally probable that the osmichloride of the first group contained water, in other words, it had not been thoroughly dried.

It would be justifiable to reject Seybold's work arbitrarily, but is perhaps better to give it some weight, and to regard the two groups as one, with a mean percentage of 43.296±.0257. This value, combined with that of Seubert, 43.459±.0036, gives a general mean of

$$Am_2OsCl_6 : Os :: 100 : 33.452 \pm .0035.$$

Seybold's deteminations practically reject themselves.

[1] Inaug. Dissertation, Erlangen, 1912.

The ratios for osmium are now as follows:

(1) Per cent Os in Am_2OsCl_6, $43.452 \pm .0035$.
(2) $6AgCl : Am_2OsCl_6 :: 100 : 51.283 \pm .0099$.
(3) $4AgCl : K_2OsCl_6 :: 100 : 84.097 \pm .0030$.
(4) Per cent Os in K_2OsCl_6, $39.553 \pm .0052$.
(5) Per cent KCl in K_2OsCl_6, $30.941 \pm .0079$.

To reduce these values we have—

Ag=107.880 ±.00016 N=14.0081±.00008
Cl=35.4605±.00011 K=39.0975±.00011
H=1.0078±.00001

Hence,

From ratio—	
4	Os=190.386±.0299
5	190.979±.0933
3	191.122±.0173
1	191.212±.0194
2	192.214±.0852
General mean	Os=191.073±.0117

This value is by no means satisfactory. New determinations of the atomic weight of osmium are needed.

IRIDIUM.

The only early determination of the atomic weight of iridium was made by Berzelius,[1] who analyzed potassium iridichloride by the same method which he employed with the platinum and the osmium salts. The result found from a single analysis was not far from Ir=196.7. This is now known to be too high. I have not, therefore, thought it worth while to recalculate Berzelius' figures, but give his estimation as it is stated in Roscoe and Schorlemmer's "Treatise on Chemistry."

In 1878 the matter was taken up by Seubert,[2] who had at his disposal 150 grammes of pure iridium. From this he prepared the iridichlorides of ammonium and potassium $(NH_4)_2IrCl_6$ and K_2IrCl_6, which salts were made the basis of his determinations. The potassium salt was dried by gentle heating in a stream of dry chlorine.

Upon ignition of the ammonium salt in hydrogen, metallic iridium was left behind in white coherent laminæ. The results obtained were as follows:

Am_2IrCl_6.	*Ir.*	*Per cent Ir.*
1.3164	0.5755	43.725
1.7122	.7490	43.745
1.2657	.5536	43.739
1.3676	.5980	43.726
2.6496	1.1586	43.739
2.8576	1.2489	43.705
2.9088	1.2724	43.742
		Mean, 43.732±.0035

Hence, Ir=193.402.

The potassium salt was also analyzed by decomposition in hydrogen with special precautions. In the residue the iridium and the potassium chloride were separated after the usual method, and both were estimated. Eight analyses gave the following weights:

K_2IrCl_6	*4Cl, loss.*	*Ir.*	*KCl.*
1.6316	0.4779	0.6507	0.5030
2.2544	.6600	.8993	.6953
2.1290	.6238	.8488	.6560
1.8632	.5457	.7430	.5745
2.6898	.7878	1.0726	.8291
2.3719	.6952	.9459	.7308
2.6092	.7641	1.0406	.8040
2.5249	.7395	1.0070	.7775

[1] Poggend. Annalen, 13, 435. 1828.

[2] Ber. Deutsch. chem. Gesell., 11, 1767. 1878.

Hence, we have the following percentages, reckoned on the original salt:

Ir.	*2KCl.*	*4Cl.*
39. 881	30. 829	29. 290
39. 890	30. 842	29. 277
39. 868	30. 813	29. 300
39. 876	30. 835	29. 289
39. 877	30. 825	29. 287
39. 879	30. 811	29. 310
39. 882	30. 814	29. 285
39. 883	30. 792	29. 288
Mean, 39. 880±. 0015	Mean, 30. 820±. 0037	Mean, 29. 291±. 0024
Ir=193. 004	192. 872	193. 293

Joly [1] studied derivatives of iridium trichloride. The salts were dried at 120°, and reduced in hydrogen. With $IrCl_3.3KCl.3H_2O$ he found as follows:

Salt.	*Ir.*	*KCl.*
1. 5950	0. 5881	0. 6803
1. 6386	. 6037	. 7000
2. 6276	. 9689	1. 1231

These data, if the weight of the salt itself is considered, give discordant results, but the ratio Ir : 3KCl : : 100 : x is satisfactory. The values of x are as follows:

115. 677
115. 952
115. 915

Mean, 115. 848±. 0583

Hence, Ir = 193.277.

The ammonium salt, $IrCl_3.3NH_4Cl$, gave the subjoined data:

Wt. of Salt.	*Wt. of Ir.*	*Per cent Ir.*
1. 5772	0. 6627	42. 017
1. 6056	. 6742	41. 990
		Mean, 42. 003±. 0094

Hence Ir = 193.282.

Analyses of ammonium iridichloride have also been made by Hoyermann [2] and Holzmann [3] in order to determine the atomic weight of iridium. In both investigations the salt was reduced to metal by heating in hydrogen, and the weights were referred to a vacuum. The data by Hoyermann are as follows:

Am_2IrCl_6.	*Ir.*	*Per cent Ir.*
1. 72348	0. 75205	43. 635
1. 77984	. 77654	43. 629
1. 78837	. 78011	43. 621
1. 51161	. 50249	43. 634
1. 73794	. 75838	43. 636
		Mean, 43. 631±. 0019

Hence, Ir = 192.610.

Holzmann's figures are—

Am_2IrCl_6.	*Ir.*	*Per cent Ir.*
1. 24179	0. 54483	43. 874
1. 09292	. 47809	43. 744
1. 15060	. 50299	43. 715
. 80243	. 35126	43. 747
. 78021	. 34119	43. 731
		Mean, 43. 734±. 0053

Hence, Ir = 193.418.

[1] Compt. Rend., 110, 1131. 1890. [2] Sitzungsb, phys. med. Soz. Erlangen, 42, 275. 1911. [3] Ibid., 44, 84. 1913.

The three series of percentages for the ammonium salt combine as follows:

Seubert	43.732±.0035
Hoyermann	43.631±.0019
Holzmann	43.734±.0053
General mean	43.688±.0016

The following ratios are now available from which to compute the atomic weight of iridium:

(1) Per cent Ir in Am_2IrCl_6, 43.688±.0035.
(2) Per cent Ir in K_2IrCl_6, 39.880±.0015.
(3) Per cent KCl in K_2IrCl_6, 30.820±.0037.
(4) Per cent 4Cl in K_2IrCl_6, 29-291±.0024.
(5) Per cent Ir in Am_3IrCl_6, 42.003±.0094.
(6) Ir : 3KCl :: 100 : 115.848±.0583.

To reduce these ratios we have—

Cl=35.4605±.00011	N=14.0081±.00008
K=39.0975±.00011	H= 1.0078±.00001

Hence,

From ratio—	
3	Ir=192.872±.0440
2	193.004±.0087
1	193.057±.0090
6	193.075±.0970
5	193.282±.0534
4	193.293±.0304
General mean	Ir=193.037±.0060

In a preliminary note Archibald[1] states that from analyses of the salt K_2IrCl_6 he has obtained the value Ir = 192.90. His complete investigation has not yet been published.

PLATINUM.

The earliest work upon the atomic weight of this metal was done by Berzelius,[2] who reduced platinous chloride and found it to contain 73.3 per cent of platinum. Hence Pt = 194.69. In a later investigation,[3] he studied potassium chloroplatinate, K_2PtCl_6. 6.981 parts of this salt, ignited in hydrogen, lost 2.024 of chlorine. The residue consisted of 2.822 platinum and 2.135 potassium chloride. From these data we may calculate the atomic weight of platinum in four ways:

1. From loss of Cl upon ignition	Pt=198.27
2. From weight of Pt in residue	" =197.42
3. From weight of KCl in residue	" =196.62
4. From ratio between KCl and Pt	" =197.10

The last of these values is undoubtedly the best, for it is not affected by errors due to the possible presence of moisture in the salt analyzed.

The work done by Andrews[4] is even less satisfactory than the foregoing, partly for the reason that its full details seem never to have been published. Andrews dried potassium chloroplatinate at 105°, and then decomposed it by means of zinc and water. The excess of zinc having been dissolved by treatment with acetic and nitric acids, the platinum was collected upon a filter and weighed, while the chlorine in the filtrate was estimated by Pelouze's method. Three determinations gave as follows for the atomic weight of platinum:

197.86
197.68
198.12
Mean, 197.887

Unfortunately, Andrews does not state how his calculations were made.

[1] Chem. News, 100, 150. 1909. Paper read before the British Association for the Advancement of Science.
[2] Poggend. Annalen 8, 177. 1826.
[3] Poggend. Annalen, 13, 468, 1828.
[4] British Assoc. Report, 1852.

In 1881 Seubert [1] published his determinations, basing them upon very pure chloroplatinates of potassium and ammonium. The ammonium salt, $(NH_4)_2PtCl_6$, was analyzed by heating in a stream of hydrogen, expelling that gas by a current of carbon dioxide, and weighing the residual metal. In three experiments the hydrochloric acid formed during such a reduction was collected in an absorption apparatus, and estimated by precipitation as silver chloride. Three series of experiments are given, representing three distinct preparations, as follows:

Series I.

Am_2PtCl_6.	*Pt.*	*Per cent Pt.*
2.1266	0.9348	43.957
1.7880	.7858	43.948
1.8057	.7938	43.960
2.6876	1.1811	43.946
4.7674	2.0959	43.963
2.0325	.8935	43.961
		Mean, 43.956±.002

Series II.

Am_2PtCl_6.	*Pt.*	*Per cent Pt.*
3.0460	1.3363	43.871
2.6584	1.1663	43.876
2.3334	1.0238	43.872
1.9031	.8351	43.881
3.1476	1.3810	43.875
2.7054	1.1871	43.889
		Mean, 43.876±.001

Another portion of this preparation, recrystallized from water, of 1.4358 grm., gave 0.6311 of platinum, or 43.955 per cent.

Series III.

Am_2PtCl_6.	*Pt.*	*Per cent Pt.*
2.5274	1.1118	43.990
3.2758	1.4409	43.986
1.9279	.8483	44.001
2.0182	.8884	44.020
1.8873	.8303	43.994
2.2270	.9798	43.996
2.4852	1.0936	44.004
2.5362	1.1166	44.026
3.0822	1.3561	43.998
		Mean, 44.001±.003

If these series are treated as independent and combined, giving each a weight as indicated by its probable error, and regarding the single experiment with preparation II as equal to one in the first series, we get a mean percentage of 43.907±.0009. On the other hand, if we regard the twenty-two experiments as all of equal weight in one series, the mean percentage of platinum becomes 43.953±.0078. Hence Pt=195.15. Upon comparing the work with that done later by Halberstadt and by Archibald, the latter mean seems the fairer one to adopt.

For the chlorine estimations in the ammonium salt, Seubert gives the subjoined data. I add in the last column the weight of salt proportional to 100 parts of silver chloride:

Am_2PtCl_6.	*Pt.*	*6AgCl.*	*Ratio.*
2.7054	1.1871	5.2226	51.802
2.2748	.9958	4.3758	51.986
3.0822	1.3561	5.9496	51.805
			Mean, 51.864±.041

Hence Pt=197.20.

[1] Ber. Deutsch. chem. Gesell., 14, 865.

The potassium salt, K_2PtCl_6, was also analyzed by ignition in hydrogen, treatment with water, and weighing both the platinum and the potassium chloride. The weights given are as follows:

K_2PtCl_6.	Pt.	2KCl.
5.0283	2.0173	1.5440
7.0922	2.8454	2.1793
3.5475	1.4217	1.0890
3.2296	1.2941	.9904
3.5834	1.4372	1.1001
4.4232	1.7746	1.3547
4.0993	1.6444	1.2589
4.4139	1.7713	1.3516

Hence we have these percentages, reckoned on the original salt:

Pt.	KCl.
40.119	30.706
40.120	30.728
40.076	30.698
40.070	30.666
40.107	30.700
40.120	30.627
40.114	30.710
40.130	30.621
Mean, 40.107±.005	Mean, 30.682±.009

Hence Pt=194.84. Hence Pt=195.05.

As with the ammonium salt, three experiments were made upon the potassium compound to determine the amount of chlorine (four atoms in this case) lost upon ignition in hydrogen. In the fourth column I add the amount of K_2PtCl_6 corresponding to 100 parts of AgCl:

K_2PtCl_6.	Pt.	4AgCl.	Ratio.
6.7771	2.7158	7.9725	85.006
3.5834	1.4372	4.2270	84.774
4.4139	1.7713	5.2144	84.648
			Mean, 84.809±.071

Hence Pt=195.31.

Halberstadt,[1] like Seubert, studied the chloroplatinates of potassium and ammonium, and also the corresponding double bromides and platinic bromide as well. The metal was estimated partly by reduction in hydrogen, as usual, and partly by electrolysis. Platinic bromide gave the following results:

I. By reduction in H.

$PtBr_4$.	Pt.	Per cent Pt.
0.6396	0.2422	37.867
1.7596	.6659	37.844
.9178	.3476	37.873
1.1594	.4388	37.847
1.9608	.7420	37.842
2.0865	.7898	37.853
4.0796	1.5422	37.852
6.8673	2.5985	37.839

II. By electrolysis.

$PtBr_4$.	Pt.	Per cent Pt.
1.2588	0.4763	37.837
1.4937	.5649	37.819
	Mean of all ten determinations,	37.847±.0033

Hence Pt=194.67.

[1] Ber Deutsch. chem. Gesell., 17, 2962. 1884.

The ammonium platinbromide, $(NH_4)_2PtBr_6$, was prepared in two ways, and five distinct lots were studied. With this salt, as well as with those which follow, the data are given in distinct series, with from one to several experiments in each group, but for present purposes it seems best to consolidate the materialand so put it in more manageable form. The percentages of platinum and weights found are as follows:

I. By reduction in H.

Am_2PtBr_6.	*Pt.*	*Per cent Pt.*
0.6272	0.1719	27.408
1.0438	.2865	27.447
1.1724	.3215	27.422
1.4862	.4076	27.426
1.0811	.2966	27.435
1.3383	.3672	27.437
1.0096	.2769	27.426
1.1935	.3269	27.390
1.3182	.3611	27.393
2.2476	.6159	27.402
1.3358	.3668	27.451
1.7859	.4899	27.431
4.1641	1.1427	27.441
1.1835	.3250	27.460
2.4003	.6591	27.459
2.5293	.6940	27.438
1.7147	.4705	27.439
2.3014	.6316	27.444
3.0052	.8245	27.435
4.8592	1.3329	27.430
1.5337	.4210	27.449
2.0373	.5594	27.457
2.0939	.5751	27.465

II. By electrolysis.

Am_2PtBr_6.	*Pt.*	*Per cent Pt.*
1.5586	0.4272	27.409
1.6052	.4397	27.392
3.1229	.8569	27.439
1.1612	.3180	27.386
2.5817	.7081	27.427
1.0231	.2809	27.456
1.6744	.4591	27.418
1.6744	.4591	27.418
1.6052	.4397	27.392

Mean of all thirty-two determinations, 27.429±.0027

Hence Pt=194.88.

With potassium platinbromide Halberstadt found as follows:

I. By reduction in H.

K_2PtBr_6.	*Pt.*	*2KBr.*	*Per cent Pt.*	*Per cent KBr.*
2.5549	0.6630	0.8071	25.940	31.590
2.6323	.6831	.8318	25.947	31.599
2.9315	.7598	.9259	25.910	31.584
3.4463	.8939	1.0895	25.938	31.613
4.0081	1.0404	1.2653	25.957	31.568
3.9554	1.0266	1.2495	25.954	31.589
2.0794	.5388	.6558	25.911	31.538
2.1735	.5635	.6849	25.926	31.511
2.3099	.5986	.7297	25.914	31.590
1.4085	.3645	.4446	25.880	31.565
2.6166	.6772	.8279	25.881	31.640
2.6729	.6923	.8469	25.900	31.684

II. By electrolysis.

K_2PtBr_6.	*Pt.*	*2KBr.*	*Per cent Pt.*	*Per cent KBr.*
2. 2110	0. 5726	0. 6997	25. 898	31. 647
3. 1642	. 8188	. 9983	25. 877	31. 550
1. 9080	. 4947	. 6025	25. 927	31. 577
1. 6754	. 4341	. 5286	25. 915	31. 550
1. 3148	. 3403	. 4160	25. 882	31. 640
1. 5543	. 4025	. 4911	25. 895	31. 596
Mean of eighteen determinations,			25. 915±. 0040	31. 591±. 0068

Hence Pt=195.09 and 195.78.

For ammonium platinchloride Halberstadt gives the following data:

I. By reduction in H.

Am_2PtCl_6.	*Pt.*	*Per cent Pt.*
1. 0604	0. 4662	43. 964
1. 3846	. 6087	43. 962
1. 5065	. 6617	43. 923
2. 3266	1. 0227	43. 956
1. 3808	. 6059	43. 880
1. 7396	. 7638	43. 906
2. 7420	1. 2068	44. 011
3. 1882	1. 4019	43. 971
5. 4644	2. 4035	43. 984
3. 4859	1. 5321	43. 951

II. By electrolysis.

Am_2PtCl_6.	*Pt.*	*Per cent Pt.*
0. 9474	0. 4161	43. 920
1. 1069	. 4865	43. 951
1. 5101	. 6634	43. 930
. 5345	. 2347	43. 910
1. 6035	. 7044	43. 928
1. 9271	. 8459	43. 894
1. 1046	. 4858	43. 979
1. 4179	. 6233	43. 959
Mean of eighteen determinations,		43. 943±. 0054

Hence Pt=195.07.

For potassium platinchloride Halberstadt's data are—

I. By reduction in H.

K_2PtCl_6.	*Pt.*	*2KCl.*	*Per cent Pt.*	*Per cent KCl.*
1. 6407	0. 6574	0. 5029	40. 069	30. 651
1. 9352	. 7757	. 5921	40. 084	30. 600
1. 5793	. 6334	. 4836	40. 106	30. 621
1. 6446	. 6595	. 5049	40. 101	30. 700
1. 0225	. 4102	. 3133	40. 117	30. 640
2. 4046	. 9641	. 7388	40. 094	30. 724
5. 8344	2. 3412	1. 7905	40. 127	30. 688
7. 1732	2. 8776	2. 1998	40. 116	30. 666

II. By electrolysis.

K_2PtCl_6.	*Pt.*	*2KCl.*	*Per cent Pt.*	*Per cent KCl.*
1. 2354	0. 4953	0. 3792	40. 092	30. 695
2. 5754	1. 0318	. 7898	40. 063	30. 667
1. 0933	. 4387	. 3355	40. 126	30. 668
1. 3560	. 5438	. 4167	40. 103	30. 730
1. 7345	. 6956	. 5298	40. 104	30. 545
2. 0054	. 8038	. 6147	40. 081	30. 652
2. 0666	. 8291	. 6356	40. 117	30. 755

K_2PtCl_6.	*Pt.*	*2KCl.*	*Per cent Pt.*	*Per cent KCl.*
1. 2759	. 5118	. 3908	40. 112	30. 629
1. 9376	. 7763	. 5927	40. 065	30. 589
2. 3972	. 9608	. 7355	40. 080	30. 681
2. 7249	1. 0929	. 8364	40. 108	30. 691
	Mean of nineteen determinations,		40. 098±. 0031	30. 663±. 0080
	Seubert found,			30. 682±. 0090
	General mean,			30. 671±. 0060

Hence Pt=194.77 and 195.35 from Halberstadt's data alone.

The work of Dittmar and M'Arthur [1] on the atomic weight of platinum is difficult to discuss and essentially unsatisfactory. They investigated potassium platinchloride and came to the conclusion that it contains traces of hydroxyl replacing chlorine and also hydrogen replacing potassium. It is also liable, they think, to carry small quantities of potassium chloride. In their determinations, which involve corrections indicated by the foregoing considerations, they are not sufficiently explicit, and give none of their actual weighings. They attempt, however, to fix the ratio 2KCl : Pt, and after a number of discordant, generally high results, they give the following data for the atomic weight of platinum based upon the assumption that 2KCl=149.182:

195. 54	195. 60
195. 48	195. 37
	Mean, 195. 50±. 0330

This ratio can also be computed from Seubert's and Halberstadt's analyses, and also the ratio 2KBr : Pt. It has not seemed necessary to do so, in view of the overwhelming weight of Archibald's more recent work.

Dittmar and M'Arthur also discuss Seubert's determinations, seeking to show that the latter also, properly treated, lead to a value nearer to 195.5 than to 195. Seubert at once replied to them,[2] pointing out that the concordance between his determinations by very different methods (a concordance verified by Halberstadt's investigation) precluded the existence of errors due to impurities such as Dittmar and M'Arthur assumed.

The recent determinations by Archibald [3] of the atomic weight of platinum were based upon analyses of the platinchlorides and platinbromides of potassium and ammonium. In these analyses every precaution was taken which modern experience had shown to be necessary. The possible presence of moisture in the several salts was carefully considered, and the potassium compounds in particular were dried at 380° to 400°. For the elaborate details of manipulation the original memoir must be consulted.

First, as to the analyses of potassium platinchloride. The salt, after thorough drying and weighing, was reduced by heating in a stream of pure hydrogen. The hydrochloric acid so formed was absorbed in water, and afterwards converted into silver chloride and weighed. Known quantities of silver were used in this operation, so that two distinct ratios were determined. From the residual mixture of potassium chloride and platinum the chloride was washed out, and its chlorine content was estimated as in the previous determinations. The metallic platinum, converted into sponge by again heating in hydrogen, was also weighed. Vacuum weights are given in all of Archibald's determinations. The weights are as follows:

K_2PtCl_6.	*Pt.*	*4AgCl.*	*2AgCl.*	*4Ag.*	*2Ag.*
1. 43605	0. 57667	1. 69324	0. 84690	1. 27475	0. 63722
1. 69914	. 68226	2. 00402	1. 00172	1. 50834	. 75401
2. 11830	. 85062	2. 49836	1. 24894	1. 88046	. 93993
2. 49734	1. 00287	2. 94462	1. 47249	2. 21626	1. 10841
.....	. 86012	.....	1. 26271	.....	. 95030
2. 20619	. 88588	2. 60135	1. 30106	1. 95842	. 97909
1. 70600	. 68486	2. 01201	1. 00580	.....	.....
1. 74397	. 70018	2. 05691	1. 02820	1. 54816	. 77402
2. 06137	. 82789	2. 43096	1. 21526	1. 82982	. 91481
2. 34095	. 93991	2. 76105	1. 38034	2. 07759	1. 03868

[1] Trans. Roy. Soc. Edinburgh, 33, 561. 1887
[2] Ber. Deutsch. chem. Gesell., 21, 2179. 1888.
[3] Proc. Roy. Soc. Edinburgh, 29, 721. 1909.

K_2PtCl_6.	Pt.	4AgCl.	2AgCl.	4Ag.	2Ag.
1.54787	0.62150	1.82560	0.91266	1.37391	0.68702
1.95944	.78694	2.31070	1.15522	1.73902	.86967
2.28366	.91697	2.69304	1.34636	2.02640	1.01338
2.27441	.91320	2.68244	1.34093	2.01870	1.00924

From these weights Archibald computes nine ratios as follows. In the first ratio I have recalculated the figures into the percentage form used for previous investigations. The other ratios are as Archibald gives them; but with the probable errors computed by myself:

Per cent Pt.	4AgCl : Pt.	2AgCl : Pt.	4AgCl : K_2PtCl_6.	2AgCl:K_2PtCl_6.
40.157	34.057	68.092	84.811	169.57
40.153	34.045	68.109	84.787	169.62
40.156	34.047	68.107	84.788	169.61
40.158	34.058	68.107	84.810	169.60
.....	.....	68.117	.....	169.61
40.154	34.055	68.089	84.810	169.57
40.144	34.039	68.091	84.791	169.62
40.149	34.040	68.098	84.786	169.61
40.162	34.056	68.125	84.797	169.62
40.151	34.042	68.093	84.785	169.59
40.152	34.044	68.098	84.787	169.60
40.161	34.056	68.120	84.799	169.62
40.154	34.050	68.107	84.799	169.62
40.151	34.045	68.102	84.789	169.62
Mean, 40.154	34.049	68.104	84.795	169.606
±.0009	±.0013	±.0020	±.0019	±.0034
Pt=195.22	195.22	195.27	195.23	195.20

4Ag : Pt.	2Ag : Pt.	4Ag : K_2PtCl_6.	2Ag : K_2PtCl_6.
45.238	90.498	112.65	225.36
45.233	90.484	112.65	225.35
45.235	90.498	112.65	225.37
45.251	90.478	112.68	225.31
.....	90.510	.....	225.36
45.234	90.480	112.65	225.33
45.227	90.460	112.65	225.31
45.244	90.499	112.65	225.33
45.240	90.488	112.68	225.37
45.236	90.463	112.66	225.30
45.252	90.487	112.68	225.31
45.251	90.486	112.70	225.35
45.237	90.484	112.67	225.36
Mean, 45.240	90.486	112.66	225.34
±.0016	±.0026	±.0030	±.0047
Pt=195.22	195.23	195.21	195.24

For the first of these ratios, the percentage of Pt in K_2PtCl_6, there are previous determinations. The three series combine thus:

Seubert	40.107 ± .0050
Halberstadt	40.098 ± .0031
Archibald	40.154 ± .0009
General mean	40.1484 ± .00085

Similarly, the ratio 4AgCl : K_2PtCl_6, as determined by Seubert, may be combined with Archibald's series. Better still the two series may be reduced to uniform type with Archibald's ratio for 2AgCl, and given in the form AgCl : K_2PtCl_6 : : 100 : x. The three series then combine as follows:

Seubert, 4AgCl	339.236 ± .2840
Archibald, 4AgCl	339.180 ± .0076
Archibald, 2AgCl	339.212 ± .0068
General mean	339.204 ± .0051

Archibald's two series of measurements of the ratios between silver and the platinchloride can also be reduced to the form $Ag : K_2PtCl_6 : : 100 : x$, and combined:

4Ag series	450.64 ± .0120
2Ag series	450.66 ± .0094
General mean	450.654 ± .0074

Archibald's data for ammonium platinchloride are rather simpler than with the potassium salt, since the total chlorine was determined at once, instead of in two portions. His weights are subjoined:

Am_2PtCl_6.	*Pt.*	*6AgCl.*	*6Ag.*
1.75088	0.76976	3.39181	2.55181
1.36500	.59997	2.64317	1.99014
1.15060	.50585	2.22810	1.67695
1.27475	.56049	2.46936	1.85794
2.54096	1.11688	4.92047	3.70420

The derived ratios are as follows:

Per cent Pt.	*6AgCl:Pt.*	*6AgCl:*Am_2PtCl_6.	*6Ag:Pt.*	*6Ag:*Am_2PtCl_6.
43.964	22.695	51.621	30.165	68.613
43.954	22.699	51.643	30.147	68.588
43.964	22.703	51.640	30.165	68.613
43.969	22.698	51.623	30.167	68.611
43.955	22.699	51.641	30.152	68.597
Mean, 43.961	22.699	51.634	30.159	68.604
± .0061	± .0031	± .0032	± .0027	± .0034
Pt=195.21	195.22	195.23	195.21	195.23

One of the ratios can be combined with Seubert's determinations, as follows:

Ratio 6AgCl: Am_2PtCl_6: : 100 : x.

Seubert	51.864 ±.0410
Archibald	51.634 ±.0032
General mean	51.636 ±.0032

For ammonium platinbromide Archibald gives these data:

Am_2PtBr_6.	*Pt.*	*6AgBr.*	*6Ag.*
1.83860	0.50497	2.91430	1.67448
2.31057	.63437	3.66269	2.10379
2.33965	.64272	3.70900	2.13049

Hence the following ratios:

Per cent Pt.	*6AgBr : Pt.*	*6AgBr :* Am_2PtBr.	*6Ag : Pt.*	*6Ag :* Am_2PtBr_6.
27.465	17.327	63.089	30.157	109.801
27.455	17.320	63.084	30.154	109.829
27.471	17.329	63.080	30.168	109.827
Mean, 27.464	17.325	63.084	30.160	109.816
±.0032	±.0018	±.0018	±.0030	±.0055
Pt=195.23	195.22	195.22	195.22	195.22

The percentage of platinum in Am_2PtBr_6 combines with Halberstadt's figures thus:

Halberstadt	27.429±.0027
Archibald	27.464±.0032
General mean	27.443±.0021

The analyses of potassium platinbromide were like those of the chloride, the bromine being estimated in two portions, 2Br and 4Br. The weights are these:

K_2PtBr_6.	*Pt.*	*4AgBr.*	*2AgBr.*	*4Ag.*	*2Ag.*
2.19076	0.56779	2.18543	1.09273	1.25544	.62770
2.42094	.62766	2.41510	1.20758	1.38761	.69378
1.78705	.46344	1.78284	.89156	1.02416	.51214
1.81840	.47156	1.81430	.90703	1.04228	.52105
2.47056	.64063	2.46507	1.23246	1.41572	.70800
2.19017	.56787	2.18525	1.09260	1.25530	.62756

From these weights nine ratios are deducible, as in the case of the platinchloride, as follows:

Per cent Pt.	*4AgBr : Pt.*	*2AgBr : Pt.*	*4AgBr : K_2PtBr_6.*	*2AgBr : K_2PtBr_6.*
25. 918	25. 981	51. 961	100. 244	200. 485
25. 926	25. 989	51. 976	100. 242	200. 479
25. 933	25. 995	51. 981	100. 236	200. 441
25. 933	25. 991	51. 990	100. 226	200. 478
25. 931	25. 988	51. 980	100. 223	200. 458
25. 928	25. 990	51. 974	100. 225	200. 455
Mean, 25. 928	25. 989	51. 977	100. 233	200. 466
±. 0015	±. 0013	±. 0027	±. 0025	±. 0048
Pt=195. 23	195. 23	195. 23	195. 23	195. 23

4Ag : Pt.	*2Ag : Pt.*	*4Ag : K_2PtBr_6.*	*2Ag : K_2PtBr_6.*
45. 226	90. 456	174. 50	349. 01
45. 233	90. 470	174. 47	348. 95
45. 251	90. 491	174. 49	348. 94
45. 243	90. 502	174. 46	348. 99
45. 251	90. 485	174. 51	348. 95
45. 238	90. 489	174. 47	349. 00
Mean, 45. 240	90. 482	174. 48	348. 97
±. 0028	±. 0045	±. 0051	±. 0085
Pt=195. 22	195. 23	195. 20	195. 22

The percentage of platinum in the platinbromide combines with Halberstadt's figures as follows:

Halberstadt	25. 915±. 0040
Archibald	25. 928±. 0015
General mean	25. 927±. 0014

Several other ratios, given in divers forms by Archibald, are also capable of consolidation. The ratio between silver bromide and potassium platinbromide, reduced to uniform type, that is, to $AgBr : K_2PtBr_6 : : 100 : x$, becomes—

2AgBr series	400. 932±. 0096
4AgBr series	400. 932±. 0100
General mean	400. 932±. 0069

For the ratio $Ag : K_2PtBr_6 : : 100 : x$ we have—

2Ag series	697. 940±. 0170
4Ag series	697. 920±. 0204
General mean	697. 936±. 0131

For the ratio $AgBr : Pt : : 100 : x$—

2AgBr series	103. 954±. 0054
4AgBr series	103. 956±. 0052
General mean	103. 955±. 0037

For the ratio $AgCl : Pt : : 100 : x$—

2AgCl series with K_2PtCl_6	136. 208±. 0040
4AgCl series with K_2PtCl_6	136. 196±. 0052
6AgCl series with Am_2PtCl_6	136. 194±. 0186
General mean	136. 203±. 0031

For the ratio $Ag : Pt : : 100 : x$—

2Ag series with K_2PtCl_6	180. 972±. 0052
4Ag series with K_2PtCl_6	180. 960±. 0064
6Ag series with Am_2PtCl_6	180. 954±. 0162
6Ag series with Am_2PtBr_6	180. 960±. 0180
2Ag series with K_2PtBr_6	180. 964±. 0090
4Ag series with K_2PtB_6r	180. 960±. 0112
General mean	180. 965±. 0034

From the last two ratios the cross ratio Ag : Cl : : 100 : 32.864 ± .0039 is deducible, which agrees closely with the measurements by Richards and Wells. From the corresponding ratios Ag : Pt and AgBr : Pt, we have the ratio Ag : Br : : 100 : 74.080 ± . 0070. These agreements with the best determinations of the silver-halogen ratios are good evidence in favor of Archibald's work.

One more series of analyses of ammonium platinchloride, by Schultz,[1] remains to be mentioned. The data, with vacuum weights, are as follows:

Am_2PtCl_6	*Pt.*	*Per cent Pt.*
3. 53199	1. 54910	43. 859
2. 31493	1. 01537	43. 862
3. 84762	1. 68867	43. 888
1. 52569	. 66953	43. 883
2. 20900	. 96880	43. 857
		Mean, 43. 870 ± . 0044

Hence, Pt = 194.49.

This percentage combines with previous determinations thus:

Seubert	43. 953 ± .0078
Halberstadt	43. 943 ± .0054
Archibald	43. 961 ± .0061
Schultz	43. 870 ± .0044
General mean	43. 9185 ± .0028

Rejecting the work of Berzelius and Andrews, the following ratios are now available from which to compute the atomic weight of platinum:

(1) Am_2PtCl_6 : Pt :: 100 : 43.9185 ± .0028.
(2) 6 Ag : Am_2PtCl_6 :: 100 : 68.604 ± .0034.
(3) 6AgCl : Am_2PtCl_6 :: 100 : 51.636 ± .0032.
(4) K_2PtCl_6 : Pt :: 100 : 40.1484 ± .00085.
(5) Ag : K_2PtCl_6 :: 100 : 450.654 ± .0074.
(6) AgCl : K_2PtCl_6 :: 100 : 339.204 ± .0051.
(7) Am_2PtBr_6 : Pt :: 100 : 27.443 ± .0021.
(8) 6Ag : Am_2PtBr :: 100 : 109.816 ± .0055.
(9) 6AgBr : Am_2PtBr_6 :: 100 : 63.084 ± .0018.
(10) K_2PtBr_6 : Pt :: 100 : 25.927 ± .0014.
(11) Ag : K_2PtBr_6 :: 100 : 697.936 ± .0131.
(12) AgBr : K_2PtBr_6 :: 100 : 400.932 ± .0069.
(13) $PtBr_4$: Pt :: 100 : 37.847 ± .0033.
(14) K_2PtCl_6 : 2KCl :: 100 : 30.671 ± .0060.
(15) K_2PtBr_6 : 2KBr :: 100 : 31.591 ± .0068.
(16) 2KCl : Pt :: 149.182 : 195.50 ± .0330.
(17) Ag : Pt :: 100 : 180.965 ± .0034.
(18) AgCl : Pt :: 100 : 136.203 ± .0031.
(19) AgBr : Pt :: 100 : 103.955 ± .0037.

The antecedent atomic weights are—

Ag = 107. 880 ± .00016	K = 39. 0975 ± .00011
Cl = 35. 4605 ± .00011	N = 14. 0081 ± .00008
Br = 79. 9228 ± .00015	H = 1. 0078 ± .00001

Hence,

From ratio—	
13	Pt = 194. 670 ± .0199
1	194. 873 ± .0158
7	195. 022 ± .0160
4	195. 179 ± .0050

[1] Inaug. Dissertation, Erlangen, 1912.

From ratio—	
8	Pt=195.194±.0356
11	195.201±.0145
5	195.208±.0081
2	195.210±.0221
10	195.217±.0112
9	195.218±.0203
14	195.222±.0710
17	195.229±.0037
12	195.230±.0130
19	195.230±.0070
18	195.234±.0045
3	195.242±.0276
6	195.259±.0074
16	195.415±.0330
15	195.777±.1222
General mean	Pt=195.213±.0020

SCANDIUM.

Cleve,[1] who was the first to make serious determinations of the atomic weight of this element, obtained the following data: 1.451 grm. of sulphate, ignited, gave 0.5293 grm. of Sc_2O_3. 0.4479 grm. of Sc_2O_3, converted into sulphate, yielded 1.2255 grm. of the latter, which, upon ignition, gave 0.4479 grm. of Sc_2O_3. Hence, for the percentage of Sc_2O_3 in $Sc_2(SO_4)_3$ we have:

36.478
36.556
36.556

Mean, 36.530±.0175

Hence, Sc=45.12.

Later results are those of Nilson,[2] who converted scandium oxide into the sulphate. I give in a third column the percentage of oxide in sulphate:

Sc_2O_3.	$Sc_2(SO_4)_3$.	*Per cent.*
0.3379	0.9343	36.166
.3015	.8330	36.194
.2998	.8257	36.187
.3192	.8823	36.178

Mean, 36.181±.004

Hence, Sc=44.09.

In 1910 Meyer and Winter [3] published a paper on the atomic weight of scandium. By the sulphate method they obtained values for Sc ranging from 44.87 to 45.37, a variation of half a unit. From analyses of the oxalate, Winter found Sc=44.86 to 45.33. One analysis of the acetylacetonate gave Sc=45.07. These values are all high, and it is probable that the material analysed contained traces of thorium. In a later research by Meyer and Goldenberg,[4] in which thorium was removed, four analyses of the sulphate gave the following results:

$Sc_2(SO_4)_3$	Sc_2O_3	*Per cent* Sc_2O_3
1.5924	0.5766	36.210
2.4207	.8765	36.209
2.6394	.9565	36.239
1.5207	.5495	36.135

Mean, 36.198±.0150

Hence, Sc=44.14.

[1] Compt. Rend., 89, 419.
[2] Compt. Rend., 91, 118.
[3] Zeitsch. anorg. Chem., 67, 398. For the detailed analyses see the University dissertation by Winter, Berlin, 1911.
[4] Chem. News, 106, 12, 1912.

There are also two analyses of scandium sulphate by Lukens,[1] as follows:

$Sc_2(SO_4)_3$.	Sc_2O_3.	*Per cent* Sc_2O_3.
0.30636	0.11134	36.343
1.14140	.41553	36.406
		Mean, 36.374±.0210

Hence, Sc = 44.66.

Disregarding the work of Meyer and Winter, which is supplanted by that of Meyer and Goldenberg, the four remaining series of analyses combine thus:

Cleve	36.530±.0175
Nilson	36.181±.0040
Meyer and Goldenberg	36.198±.0150
Lukens	36.374±.0210
General mean	36.288±.0020

Hence, if S = 32.065 ± .00012, Sc = 44.403 ± .0044. This result is by no means satisfactory.

ADDENDA.

Since the manuscript of this volume was sent to the printer, important determinations of the atomic weight of scandium have been received. Hönigschmid,[2] from very exact analyses of scandium bromide, has obtained the following results. Two series, with vacuum weights, are treated here as one.

$ScBr_3$.	*Ag.*	*At.wt.Sc.*
2.79839	3.17972	45.079
3.32001	3.77235	45.084
3.34311	3.79829	45.108
3.22367	3.66250	45.114
3.11816	3.54255	45.120
2.33284	2.63915	45.103
3.13467	2.42519	45.122
1.96690	2.23460	45.120
3.13887	3.55645	45.091
2.92675	3.32529	45.103
3.14889	3.57784	45.090
2.79650	3.17719	45.113
2.80219	3.18371	45.108
2.62351	2.98093	45.087
2.59879	2.95270	45.100
2.60299	2.95768	45.080
2.37863	2.70257	45.099
1.41354	1.60630	45.054
		Mean, 45.099

The material from which Hönigschmid prepared his bromide had been purified by methods described by Meyer and Schweig,[3] who also determined the atomic weight of scandium by the usual sulphate method. The value found ranged from 45.03 to 45.37; in mean, Sc = 45.23. They show, however, that the sulphate method is untrustworthy, and accept Hönigschmid's determination, rounded off to 45.1. This value should replace the older one, but it agrees with the earliest of all, that by Cleve.

[1] Journ. Amer. Chem. Soc., 35, 1470. 1913. [2] Zeitschr. Electrochem., 25, 93. 1919. [3] Zeitschr. anorg. allg. Chemie, 108, 303. 1919.

YTTRIUM.

Nearly all the regular determinations of the atomic weight of yttrium depend upon analyses or syntheses of the sulphate. A series of analyses of the oxalate, however, by Berlin,[1] is sometimes cited, and the data are as follows. In three experiments upon the salt $Yt_2(C_2O_4)_3.3H_2O$ the subjoined percentages of oxide were found:

45.70
45.65
45.72
Mean, 45.69±.0141

Hence Yt=89.60.

The early work of Berzelius [2] may be ignored. The determinations by Popp,[3] Delafontaine,[4] and Bahr and Bunsen [5] are also of no present value. They are sufficiently summarized in the former editions of this work.

The first determinations of the atomic weight of yttrium which have any real significance are those by Cleve and Hoeglund,[6] who adopted the method of converting the oxide into the anhydrous sulphate. Their data are as follows:

Yt_2O_3.	$Yt_2(SO_4)_3$.	Per cent Yt_2O_3.
1.4060	2.8925	48.608
1.0930	2.2515	48.545
1.4540	2.9895	48.637
1.3285	2.7320	48.627
2.3500	4.8330	48.624
2.5780	5.3055	48.591
		Mean, 48.605±.0096

Hence Yt=89.58.

In a later paper Cleve [7] gives syntheses of yttrium sulphate made with yttria which was carefully freed from terbia. The weights and percentages are as follows:

Yt_2O_3.	$Yt_2(SO_4)_3$.	Per cent Yt_2O_3.
0.8786	1.8113	48.507
.8363	1.7234	48.526
.8906	1.8364	48.497
.7102	1.4645	48.494
.7372	1.5194	48.519
.9724	2.0047	48.506
.9308	1.9197	47.487
.8341	1.7204	48.483
1.0224	2.1073	48.517
.9384	1.9341	48.519
.9744	2.0093	48.494
1.5314	3.1586	48.484
		Mean, 48.503±.0029

Hence Yt=89.12.

The yttria studied by Jones [8] had been purified by Rowland's method—that is, by precipitation with potassium ferrocyanide—and certainly contained less than one-half of one per cent of other rare earths as possible impurities. Two series of determinations were made—one by ignition of the sulphate, the other by its synthesis. The results were as follows, with the usual percentage column added:

[1] Forhandlingar ved de Skandinaviske Naturforskeres, 8, 452. 1880.
[2] Lehrbuch, 5 Aufl. 2, 1225.
[3] Ann. Chem. Pharm., 131, 179. 1864.
[4] Ann. Chem. Pharm., 134, 108. 1865. Second paper in Arch. Sci. Phys. Nat. (2), 25, 119. 1866.
[5] Ann. Chem. Pharm., 137, 21. 1866.
[6] K. Svenska Vet. Akad. Handlingar, Bd. 1, No. 8. 1873.
[7] K. Svenska Vet. Akad. Handlingar, No. 9, 1882. See also Bull. Soc. Chim., 39, 120. 1883
[8] Amer. Chem. Journ., 17, 154. 1895.

First series. Syntheses.

Yt_2O_3.	$Yt_2(SO_4)_3$.	*Per cent* Yt_2O_3.
0.2415	0.4984	48.455
.4112	.8485	48.462
.2238	.4617	48.473
.3334	.6879	48.466
.3408	.7033	48.457
.3418	.7049	48.489
.2810	.5798	48.465
.3781	.7803	48.456
.4379	.9032	48.483
.4798	.9901	48.460

Mean, 48.467±.0025

Second series. Analyses.

$Yt_2(SO_4)_3$.	Yt_2O_3.	*Per cent* Yt_2O_3.
0.5906	0.2862	48.459
.4918	.2383	48.455
.5579	.2705	48.485
.6430	.3117	48.478
.6953	.3369	48.454
1.4192	.6880	48.478
.8307	.4027	48.477
.7980	.3869	48.484
.8538	.4139	48.477
1.1890	.5763	48.469

Mean, 48.472±.0024

From syntheses.....Yt=88.95
From analyses.....Yt=88.97

These data of Jones were briefly criticized by Delafontaine,[1] who regards a lower value as more probable. In a brief rejoinder[2] Jones defended his own work; but neither the attack nor the reply needs further consideration here. They are referred to merely as part of the record.

By Muthmann and Böhm[3] there is a single determination. 2.46505 grammes $Yt_2(SO_4)_3$ gave 1.19511 Yt_2O_3. Per cent Yt_2O_3, 48.482, and Yt=89.02.

In a preliminary note, G. and E. Urbain[4] state that Yt=88.6, but they give no details. Three determinations by Bodman[5] are as follows:

Yt_2O_3.	$Yt_2(SO_4)_3$.	*Per cent* Yt_2O_3.
0.4381	0.8928	49.070
.5929	1.2093	49.028
.4062	.8286	49.022

Mean, 49.040±.0102

Hence, Yt=91.57.

The little known analyses of yttrium sulphate by Postius[6] are as follows:

$Yt_2(SO_4)_3$.	Yt_2O_3.	*Per cent* Yt_2O_3.
0.32243	0.15588	48.345
.20460	.09897	48.370
.68477	.33120	48.367
.24013	.11606	48.332
.51195	.24792	48.315
.56165	.27161	48.354
.53310	.25770	48.340

Mean, 48.347±.0160.

Hence, Yt=88.41.

[1] Chem. News, 71, 243.
[2] Chem. News, 71, 305.
[3] Ber. Deutsch. chem. Ges., 33, 42. 1900.
[4] Compt. Rend., 132, 136. 1901.
[5] Bihang Svensk. Vet. Akad. Handl., 26 (2), No. 3. 1901.
[6] Dissertation, Techn. Hochschule, München, 1902.

Meyer and Wuorinen[1] also studied yttrium sulphate. Five syntheses from the oxide were first made, which gave low values for the atomic weight of yttrium, due to acidity of the sulphate. Two more syntheses followed, in which the excess of acid was determined, with these results:

Yt_2O_3.	$Yt_2(SO_4)_3$.	*Per cent* Yt_2O_3.
0.5544	1.1452	48.411
.9003	1.8595	48.402
		Mean, 48.406±.0034.

Hence, Yt=88.68.

The work of Meyer and Weinhaber[2] is essentially a continuation of the foregoing research. Two series of determinations were made, one synthetic and one analytic, with due precautions against acidity of the yttrium sulphate. The data are as follows:

Syntheses.

Yt_2O_3.	$Yt_2(SO_4)_3$.	*Per cent* Yt_2O_3.
0.4954	1.0231	48.421
.4972	1.0266	48.432
.4980	1.0286	48.415
		Mean, 48.423±.0034

Hence, Yt=88.75.

Analyses.

$Yt_2(SO_4)_3$.	Yt_2O_3.	*Per cent* Yt_2O_3.
1.0248	0.4962	48.419
.8585	.4157	48.422
1.4060	.6808	48.421
.8944	.4330	48.412
.8975	.4743	48.423
.5686	.2753	48.417
		Mean, 48.419±.0011

Hence, Yt=88.73.

Syntheses of yttrium sulphate have also been effected by Egan and Balke.[3] Their determinations, which they regard as not altogether satisfactory, are as follows:

Yt_2O_3.	$Yt_2(SO_4)_3$.	*Per cent* Yt_2O_3.
1.00552	2.06854	48.612
.87756	1.79829	48.912
.20640	.42557	48.500
.19823	.40993	48.357
.26409	.54237	48.357
.36243	.74383	48.725
.34745	.71295	48.734
.28690	.58787	48.803
.22910	.47098	48.643
.27464	.56434	48.666
.18760	.38580	48.626
		Mean, 48.630±.0334

Hence, Yt=89.69.

There are also two determinations by Brill,[4] made with the microbalance. The percentages of Yt_2O_3 in the sulphate are:

48.647
48.617

Mean, 48.632±.0100.

Hence, Yt=89.70.

For the percentage of yttria in the sulphate we now have the following data, to be combined in the usual way. The one determination by Muthmann and Böhm is arbitrarily given equal weight with the figure assigned to Brill:

[1] Zeitsch. anorg. Chem., 80, 26. 1913.
[2] Ber. Deutsch. chem. Ges., 46, 2672. 1913.
[3] Journ. Amer. Chem. Soc., 35, 365. 1913.
[4] Zeitsch. anorg. Chem., 47, 464. 1905.

Cleve and Hoeglund	48.605±.0096
Cleve, later	48.503±.0029
Jones, syntheses	48.467±.0025
Jones, analyses	48.472±.0024
Muthmann and Böhm	48.482±.0100
Bodman	49.040±.0102
Brill	48.632±.0100
Postius	48.347±.0160
Meyer and Wuorinen	48.406±.0034
Meyer and Weinhaber, syntheses	48.423±.0034
Meyer and Weinhaber, analyses	48.419±.0011
Egan and Balke	48.630±.0334
General mean	48.444±.0008

Hence, Yt=88.848±.0016.

An entirely different method for determining the atomic weight of yttrium was adopted by Egan and Balke.[1] The oxide was converted into chloride by solution in aqueous hydrochloric acid, and the chloride was afterward dehydrated by careful heating in a stream of dry, gaseous hydrochloric acid. The weights given and the ratios $2YtCl_3 : Yt_2O_3 :: 100 : x$ are as follows:

Yt_2O_3.	$YtCl_3$.	*Ratio.*
0.72180	1.24092	58.167
.80392	1.38437	58.072
.70050	1.20610	58.080
.73030	1.25755	58.073
	Mean,	58.098±.0155

Hence, Yt=90.22.

A second series of determinations of this ratios is due to Hopkins and Balke.[2] Their figures are—

Yt_2O_3.	YCl_3.	*Ratio.*
0.56492	0.97718	57.811
.51059	.88348	57.813
.64232	1.11092	57.819
.82157	1.42087	57.820
.68246	1.17975	57.848
.54164	.93688	57.812
	Mean,	57.820±.0042

Hence, Yt=88.93.

The two series combined give a general mean of 57.839±.0040, from which Yt=89.016±.0180.

The determinations made by Feit and Przibylla,[3] by their volumetric method, are as follows:

Yt_2O_3.	*O.*	*Atomic weight.*
0.3677	0.07781	89.415
.4928	.10438	89.309
.3660	.07749	89.356
.3660	.07751	89.328
.3704	.07840	89.387
.3635	.07701	89.284
	Mean,	89.346±.0135

Computing with S=32.065±.00012, and Cl=35.4605±.00011, we have these three values for the atomic weight of yttrium:

From the sulphate	Yt=88.848±.0016
From the chloride	89.016±.0180
From the oxide	89.346±.0135
General mean	Yt=88.856±.0016

The sulphate ratios alone dominate this combination.

[1] *Loc. cit.* [2] Journ. Amer. Chem. Soc., 38, 2332. 1916. [3] Zeitschr. anorg. Chem., 50, 262, 1906. For the process, see under lanthanum.

ADDENDUM.

The determinations of the atomic weight of yttrium by Kremers and Hopkins[1] appeared after the manuscript of this book had passed out of the author's hands. They determined the ratio between yttrium chloride and silver by the standard method. Their figures, with vacuum weights, are as follows:

$YtCl_3$.	*Ag.*	*At.wt. Yt.*
3.31143	5.47636	89.32
2.31979	3.83587	89.34
2.26815	3.75045	89.35
2.29376	3.79302	89.33
2.200731	3.31977	89.31
1.97610	3.26827	89.30
2.17949	3.60389	89.34
		Mean, 89.33

As the method employed by Kremers and Hopkins is more trustworthy than the older ones, their value for yttrium should be provisionally accepted.

LANTHANUM.

The early attempts to determine the atomic weight of lanthanum by Mosander and by Choubine were only rough approximations to the true value, and have no modern significance. The determinations by Rammelsberg,[2] Holzmann,[3] Czudnowicz,[4] Hermann,[5] Zschiesche,[6] and Erk,[7] and also the earliest measurements by Marignac,[8] may also be disregarded as of no present value. They are sufficiently discussed in the previous editions of this work. A later research by Marignac,[9] however, is entitled to consideration here. His starting point was the sulphate of lanthanum, purified by repeated crystallizations. In two determinations the salt was calcined, and the residual oxide weighed; in two others the lanthanum was precipitated as oxalate, and converted into oxide by ignition. The data follow:

$La_2(SO_4)_3$.	La_2O_3.	*Per cent* La_2O_3.
2.0988	1.2082	57.566
2.3504	1.3532	57.573
2.8113	1.6165	57.500
3.3385	1.9215	57.556
		Mean, 57.549±.0112

Hence, La = 138.81.

From Cleve we have two separate investigations relative to the atomic weight of lanthanum. In his first series[10] strongly calcined La_2O_3 spectroscopically pure, was dissolved in nitric acid and then, by evaporation with sulphuric acid, converted into sulphate:

La_2O_3.	*Sulphate.*	*Per cent.*
1.9215	3.3365	57.590
2.0570	3.5705	57.611
1.6980	2.9445	57.667
2.0840	3.6170	57.617
1.9565	3.3960	57.612
		Mean, 57.619±.0085

Hence, La = 139.28.

In his second paper,[11] published nine years later, Cleve gives results similarly obtained, but with lanthanum oxide much more completely freed from other earths. The data are as follows, lettered to correspond to different fractions of the material studied:

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[1] Journ. Amer. Chem. Soc., 41, 718. 1919.
[2] Poggend. Annalen, 55, 65. 1842.
[3] Journ. prakt. Chem. 75, 321. 1858.
[4] Ibid., 80, 33. 1860.
[5] Ibid., 82, 396. 1861.
[6] Ibid., 104, 174.
[7] Jenaisches Zeitschrift, 6, 396. 1871.
[8] Arch. Sci. Phys. Nat., (1), 11, 29. 1849. Oeuvres Complétes, 1, 230.
[9] Ibid., (4), 30, 68, 1873. O. C. 2, 566.
[10] K. Svensk. Vet. Akad. Handlingar, Bd. 2, No. 7. 1874.
[11] K. Svensk. Vet. Akad. Handlingar, No. 2, 1883.

	La_2O_3.	*Sulphate.*	*Per cent.*
B	0.8390	1.4600	57.466
C	1.1861	2.0643	57.458
	.8993	1.5645	57.482
	.8685	1.5108	57.486
	.8515	1.4817	57.468
D	.6486	1.1282	57.490
	.7329	1.2746	57.500
E	1.2477	2.1703	57.490
F	1 1621	2.0217	57.481
	1.5749	2.7407	57.463
G	1.3367	2.3248	57.497
	1.4455	2.5146	57.484

Mean, 57.480±.0040

Hence, La = 138.35.

Brauner, in 1882, published two sets of determinations, both based upon the conversion of pure La_2O_3 into $La_2(SO_4)_3$.

In his first paper, Brauner [1] gives only two syntheses, as follows:

La_2O_3.	$La_2(SO_4)_3$.	*Per cent.*
1.75933	3.05707	57.566
.92417	1.60589	57.549

Mean, 57.5575±.0057

Hence, La = 138.87.

In Brauner's second [2] paper six determinations are given, one being affected by a misprint, which is corrected by a citation in Abegg's Handbuch:[3]

La_2O_3.	$La_2(SO_4)_3$.	*Per cent.*
0.7850	1.3658	57.476
2.3500	4.0917	57.433
2.1052	3.6633	57.467
1.0010	1.7411	57.525
1.3807	2.4021	57.479
1.5275	2.6588	57.451

Mean, 57.472±.0086

Hence, La = 138.30.

Brauner's weighings are all reduced to a vacuum.

Both Bauer and Bettendorff made their determinations of the atomic weight of lanthanum by the same general method. Bauer's data [4] are as follows:

La_2O_3.	*Sulphate.*	*Per cent.*
0.6431	1.1171	57.569
.7825	1.3613	57.482
1.0112	1.7571	57.549
.7325	1.2725	57.564

Mean, 57.541±.0136

Hence, La = 138.76.

Bettendorff found [5]—

La_2O_3.	*Sulphate.*	*Per cent.*
0.9146	1.5900	57.522
.9395	1.6332	57.525
.9133	1.5877	57.523
1.0651	1.8515	57.526

Mean, 57.524±.0006

Hence, La = 138.65.

[1] Monats. Chem., 3, 1.
[2] Monats. Chem., 3, 486.
[3] Band 3, Abth. 1, p. 240. Brauner's discussion of the atomic weight.
[4] Inaugural Dissertation, Freiburg, 1884.
[5] Liebig's Annalen, 256, 168. 1890.

The few determinations by Wolcott Gibbs[1] were made by the oxalate method, which is described in the chapter on cerium. His purpose, however, was rather to test the method than to definitely fix an atomic weight. The data given are as follows, with the ratio $3C_2O_3$: La_2O_3 added:

La_2O_3.	C_2O_3.	Ratio.
45.61	30.15	151.327
46.64	30.07	151.729
	30.08	151.679
Mean, 45.625	30.11	151.528
		Mean, 151.566±.0607

Hence, La = 139.70.

Gibbs cites three determinations, by the same method, made by Shapleigh, who found La = 139.75, 139.72 and 139.67. The weighings, however, are not given, and the data are unavailable for present purposes.

In 1901 Bodman[2] published three determinations, based on syntheses of lanthanum sulphate. The figures are:

La_2O_3.	$La_2(SO_4)_3$.	Per cent La_2O_3.
0.4038	0.7013	57.579
.4408	.7660	57.546
.4467	.7758	57.579
		Mean, 57.568±.0070

Hence, La = 138.94.

In 1902 Jones[3] published his elaborate series of determinations, based upon scrupulously purified materials. He effected twelve syntheses of lanthanum sulphate from the oxide, and examined his product carefully for acid sulphate, whose presence would tend to lower the apparent atomic weight of the metal. This source of error Jones regards as excluded from his determinations. His results are as follows:

La_2O_3.	$La_2(SO_4)_3$.	Per cent La_2O_3.
1.0122	1.7592	57.538
1.1268	1.9581	57.546
.94585	1.6437	57.543
1.0675	1.8553	57.538
.9030	1.5692	57.545
1.1273	1.9589	57.548
.9407	1.6347	57.546
1.0455	1.8168	57.546
1.1271	1.9586	57.546
1.3074	2.2720	57.544
1.3389	2.3267	57.545
1.2012	2.0874	57.545
		Mean, 57.544±.0006

Hence, La = 138.78.

The atomic weight determinations by Brauner and Pavliček[4] included a study of both the sulphate and the oxalate methods. In lanthanum sulphate the acid salt was always found to be present, and its amount was determined by titration, with sodium hydroxide, using ethyl-orange as an indicator. The excess of acid thus measured tends to lower the apparent atomic weight of lanthanum, and Brauner argues very forcibly that all previous determinations of atomic weights among the rare earths are vitiated by this error. The authors give three series of syntheses of the sulphate, in which corrections for the acid salt are applied. First, there is a preliminary series, with weights in air. The data, with the acid correction, are as follows, representing eight different fractions of the oxide:

[1] Proc. Amer. Acad., 28, 260. 1893.
[2] Bihang Svensk. Vet. Akad. Handl., 26 (2), No. 3. 1901.
[3] Amer. Chem. Journ., 28, 23. 1902.
[4] Journ. Chem. Soc., 81, 1243. 1902. Preliminary notice in Proc. Chem. Soc., 17, 63. 1901.

La_2O_3.	$La_2(SO_4)_3$.	Per cent La_2O_3.
0.93205	1.6198	57.541
.8416	1.46234	57.552
.85993	1.49440	57.543
.7847	1.3635	57.550
.80645	1.40145	57.544
1.0760	1.86913	57.567
[1] 1.0683	[1] 1.51479	57.572
.8721	1.51449	57.584
.9755	1.69381	57.592
.9188	1.5955	57.587
.9507	1.65040	57.604
.9677	1.68062	57.580
.8570	1.48736	57.619
		Mean, 57.572±.0047

Corrected to a vacuum this mean becomes 57.564±.0047. Hence, La=138.91. Its significance, however, is diminished by the fact that the fractions show a progressive change in composition, which appears in the percentage column. The later fractions are higher in La_2O_3 than the earlier ones.

The next set of syntheses, representing a different series of lanthanum preparations, gave the subjoined results, corrected for acid sulphate, but with weights in air:

La_2O_3.	$La_2(SO_4)_3$.	Per cent La_2O_3.
0.8262	1.4353	57.563
.95652	1.66133	57.576
.45780	.79574	57.538
1.34754	2.34074	57.569
1.17280	2.03804	57.545
		Mean, 57.558±.0048

Corrected for weighing in air this becomes 57.550. La=138.82.

This series, like the preceding one, is given by Brauner and Pavliček as preliminary to more exact work, which seems to have been continued by Brauner alone. His final series of figures, determined with extreme care, and with all corrections applied, including the reduction to a vacuum, follows:

La_2O_3.	$La_2(SO_4)_3$.	Per cent La_2O_3.
1.06562	1.85054	57.5843
1.00694	1.74856	57.5868
1.12553	1.95457	57.5845
1.70276	2.95707	57.5827
1.02460	1.77943	57.5802
1.28650	2.23419	57.5824
1.06488	1.84910	57.5891
		Mean, 57.5843±.00075

Hence, La=139.05.

The oxalate series of determinations by Brauner and Pavliček is less satisfactory than this sulphate series, although it leads to sensibly the same value for the atomic weight of lanthanum. Rejecting one experiment in their series, which is thrown out as abnormal by the authors, their percentages are as given in the next table, together with the usual ratios:

Per cent C_2O_3.	Per cent La_2O_3.	Ratio.
31.041	46.884	151.039
	46.876	151.013
29.673	44.722	150.716
	44.711	150.679
	44.694	150.622
	44.719	150.706
	44.746	150.797

[1] These weights are erroneous, either through misprinting in the original or because of copying. The percentage given is that calculated by Brauner and Pavliček

Per cent C_2O_3.	*Per cent La_2O_3.*	*Ratio.*
29.755	44.879	150.828
	44.845	150.714
31.920	48.197	150.993
29.689	44.751	150.733
30.883	46.719	151.277
	46.678	151.145
31.762	48.129	151.530
	48.118	151.495
	48.133	151.543
		Mean, 150.989±.0543

Hence, La=139.08.

The Gibbs value for the same ratio is 151.566±.0607. The general mean of both series is 151.246±.0400.

In a criticism of Jones' determinations by the sulphate method Brauner [1] reiterates his statements concerning the acid salt, and also suggests other sources of error, such as contamination of the lanthanum preparations by cerium, and losses by spattering. To this criticism Jones [2] promptly replied, giving a new series of determinations as follows:

La_2O_3.	*$La_2(SO_4)_3$.*	*Per cent La_2O_3.*
1.2161	2.1132	57.548
1.6311	2.8342	57.551
1.7804	3.0938	57.547
1.4168	2.4619	57.549
1.9702	3.4235	57.549
		Mean, 57.549±.0010

Hence, La=138.81.

The material was spectroscopically pure, and the sulphate was neutral and soluble. The operations were performed in porcelain crucibles, and the oxide was perfectly white. Brauner used platinum crucibles, and Jones found that lanthanum oxide, heated in platinum, became perceptibly discolored. Two determinations made in platinum gave the following results:

La_2O_3.	*$La_2(SO_4)_3$.*	*Per cent La_2O_3.*
1.2820	2.2264	57.582
1.3885	2.4110	57.590
		Mean, 57.586±.0027

Hence, La=139.06, a value in accord with Brauner's. According to Jones the discoloration and variation in atomic weight suggest the presence of some other oxide than the normal compound in Brauner's preparations. The controversy, however, remains unsettled, and additional investigations are needed to determine the truth.

The two determinations by Brill [3] are of slight value, and hardly worth considering. Small quantities of lanthanum sulphate were calcined to oxide, and the weighings were made with the Nernst microbalance, in order to test its applicability to work of this kind. The percentages of oxide in sulphate are given below, more for the sake of completeness than for any real significance in them:

57.664
57.726
Mean, 57.695±.0207

Hence, La=139.79, a very high value.

In 1906 Feit and Pryzibylla [4] determined the atomic weights of several rare earth metals by a special volumetric process, which, however, seems to be approximate rather than exact. In each case the weighed oxide was dissolved in an excess of half-normal sulphuric acid, the excess being afterwards measured by titration with tenth-normal sodium hydroxide solution.

[1] Zeitsch. anorg. Chem., 33, 317. 1903.
[2] Zeitsch. anorg. Chem., 36, 92. 1903. Chem. News, 88, 13.
[3] Zeitsch. anorg. Chem., 47, 464. 1905.
[4] Zeitsch. anorg. Chem., 50, 248. 1906. See also an earlier paper in Vol. 43, p. 213. 1905.

From the data thus obtained, by a process which is not clearly explained, the authors compute the proportion of oxygen in the oxides, and thence deduce the atomic weights of the several measurements. It would have been better to have given the H_2SO_4 equivalent to the oxide, and then to have made a more direct calculation. However, I cite the determinations for what they may be worth, their value being essentially corroborative. For lanthanum the authors give the following determinations:

La_2O_3.	O.	Atomic weight.
0.5125	0.07544	139.05
.5256	.07731	139.11
.4835	.07116	139.08
.5235	.07706	139.04
.4815	.07088	139.03
.5156	.07585	139.15
.5348	.07867	139.15
		Mean, 139.09±.0430

For the percentage of oxide in sulphate we have estimates as follows:

Marignac	57.549 ±.0112
Cleve, earlier series	57.619 ±.0085
Cleve, later series	57.480 ±.0040
Brauner, 1882, first series	57.5575±.0057
Brauner, 1882, second series	57.472 ±.0086
Bauer	57.541 ±.0136
Bettendorff	57.524 ±.0006
Bodman	57.568 ±.0070
Jones, 1902	57.544 ±.0006
Brauner and Pavliček, first	57.564 ±.0047
Brauner and Pavliček, second	57.550 ±.0048
Brauner and Pavliček, third	57.5843±.00075
Jones, 1903, porcelain series	57.549 ±.0010
Jones, 1903, platinum series	57.586 ±.0027
Brill	57.695 ±.0207
General mean	57.5465±.00034

This mean agrees very closely with the figures given by Jones.

There are now three ratios from which to deduce the atomic weight of lanthanum:

(1) $La_2(SO_4)_3 : La_2O_3 :: 100 : 57.5465 \pm .00034$.
(2) $3\ C_2O_3 : La_2O_3 :: 100 : 151.246 \pm .0400$.
(3) $O : La :: 16 : 139.09 \pm .0430$.

Reducing these with $S = 32.065 \pm .00012$, and $C = 12.0025 \pm .00019$, we have—

From ratio—	
1	La=138.800±.0015
2	139.090±.0430
3	139.357±.0303

It is evidently unnecessary to combine these values into a general mean, for only one of them, that from ratio 1, carries any appreciable weight. The other values could not modify it to any noteworthy extent. The value La = 138.8 is essentially that found by Jones, whose work is entitled to high credit. Brauner, however, by two distinct methods, found La = 139, with much to be said in favor of his determinations. The question as to the true atomic weight of lanthanum is therefore not closed; and it should be taken up anew by means of other methods than those heretofore employed.

CERIUM.

Although cerium was discovered almost at the beginning of the nineteenth century, its atomic weight could not be properly determined until after the discovery of lanthanum and "didymium" by Mosander. The early attempts at the determination, however, may now be disregarded, as having only historical interest. These attempts, by Beringer,[1] Hermann,[2] Marignac,[3] Kjerulf,[4] Bunsen and Jegel,[5] and Rammelsberg,[6] are all sufficiently summarized in the former editions of this work.

In all of these early determinations the ceric oxide obtained was somewhat colored, the tint ranging from one shade to another of light brown, according to the amount of didymium present. Still, at the best, a color remained, which was supposed to be characteristic of the oxide itself. In 1868, however, some experiments of Dr. C. Wolf [7] were posthumously made public, which went to show that pure ceroso-ceric oxide is white, and that all samples previously studied were contaminated with some other earth, not necessarily didymium but possibly a new substance, the removal of which tended to lower the apparent atomic weight of cerium very perceptibly.

Cerium sulphate was recrystallized at least 10 times. Even after 20 recrystallizations it still showed spectroscopic traces of didymium. The water contained in each sample of the salt was cautiously estimated, and the cerium was thrown down by boiling concentrated solutions of oxalic acid. The resulting oxalate was ignited with great care. I deduce from the weighings the percentage of CeO_2 given by the *anhydrous* sulphate:

Sulphate.	*Water.*	*CeO_2.*	*Per cent CeO_2.*
1.4542	0.19419	0.76305	60.559
1.4104	.1898	.7377	60.437
1.35027	.1820	.70665	60.487
			Mean, 60.494

After the foregoing experiments the sulphate was further purified by solution in nitric acid and pouring into a large quantity of boiling water. The precipitate was converted into sulphate and analyzed as before:

Sulphate.	*Water.*	*CeO_2.*	*Per cent CeO_2*
1.4327	0.2733	0.69925	60.311
1.5056	.2775	.7405	60.296
1.44045	.2710	.7052	60.300
			Mean, 60.302

From another purification the following weights were obtained:

1.4684 grm. 0.1880 grm. 0.7717 grm. 60.270 per cent.

A last purification gave a still lower percentage:

1.3756 grm. 0.1832 grm. 0.7186 grm. 60.265 per cent.

The last oxide was perfectly white, and was spectroscopically free from didymium. In each case the CeO_2 was titrated iodometrically for its excess of oxygen. It will be noticed that in the successive series of determinations the percentage of CeO_2 steadily and strikingly diminishes to an extent for which no ordinary impurity of didymium can account. The death of Dr. Wolf interrupted the investigation, the results of which were edited and published by Professor F. A. Genth.

In the light of more recent evidence, little weight can be given to these observations. All the experiments, taken equally, give a mean percentage of CeO_2 from $Ce_2(SO_4)_3$ of $60.366 \pm .0308$. This mean has obviously little or no real significance. It gives $Ce = 138.73$.

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[1] Ann. Chem. Pharm., 42, 134. 1842.
[2] Journ. prakt. Chem., 20, 185. 1843.
[3] Arch. Sci. Phys. Nat. (1), 8, 273. 1848. Ouevres Complètes, 1, 215.
[4] Ann. Chem. Pharm., 87, 12.
[5] Ibid., 105, 45. 1858.
[6] Poggend. Annal en, 55, 65; 108, 44.
[7] Amer. Journ. Sci. (2), 46, 53. 1868.

The determination of Wolf attracted little attention, except from Wing,[1] who partially verified certain aspects of them. This chemist, incidentally to other researches, purified some cerium sulphate after the method of Wolf, and made two similar analyses of it, as follows:

Sulphate.	*Water.*	*CeO_2.*	*Per cent. CeO_2.*
1. 2885	0. 1707	0. 6732	60. 225
1. 4090	. 1857	. 7372	60. 263
			Mean, 60. 244

Hence, Ce = 137.87.

The ceric oxide in this case was perfectly white. The cerium oxalate which yielded it was precipitated boiling by a boiling concentrated solution of oxalic acid. The precipitate stood twenty-four hours before filtering.

In 1875 Buehrig's[2] paper upon the atomic weight of cerium was issued. He first studied the sulphate, which, after eight crystallizations, still retained traces of free sulphuric acid. He found, furthermore, that the salt obstinately retained traces of water, which could not be wholly expelled by heat without partial decomposition of the material. These sources of error probably affect all the previously cited series of determinations, although, in the case of Wolf's work, it is doubtful whether they could have influenced the atomic weight of cerium by more than one or two-tenths of a unit. Buehrig also found, as Marignac had earlier shown, that upon precipitation of cerium sulphate with barium chloride the barium sulphate invariably carried down traces of cerium. Furthermore, the ceric oxide from the filtrate always contained barium. For these reasons the sulphate was abandoned, and the atomic weight determinations of Buehrig were made with air-dried oxalate. This salt was placed in a series of platinum boats in a combustion tube behind copper oxide. It was then burned in a stream of pure, dry oxygen, and the carbonic acid and water were collected after the usual method. Ten determinations were made; in all of them the above-named products were estimated, and in five analyses the resulting ceric oxide was also weighed. By deducting the water found from the weight of the air-dried oxalate, the weight of the anhydrous oxalate is obtained, and the percentages of its constituents are easily determined. In weighing, the articles weighed were always counterpoised with similar materials. The following weights were found:

Oxalate.	*Water.*	*CO_2.*	*CeO_2.*
9. 8541	2. 1897	3. 6942	.....
9. 5368	2. 1269	3. 5752	.....
9. 2956	2. 0735	3. 4845	.....
10. 0495	2. 2364	3. 7704	.....
10. 8249	2. 4145	4. 0586	.....
9. 3679	2. 0907	3. 5118	4. 6150
9. 7646	2. 1769	3. 6616	4. 8133
9. 9026	2. 2073	3. 7139	4. 8824
9. 9376	2. 2170	3. 7251	4. 8971
9. 5324	2. 1267	3. 5735	4. 6974

These figures give us the following percentages for CO_2 and CeO_2 in the anhydrous oxalate:

CO_2.	*CeO_2.*
48. 256	.....
48. 249	.....
48. 248	.....
48. 257	.....
48. 257	.....
48. 258	63. 417
48. 257	63. 436
48. 262	63. 446
48. 249	63. 429
48. 253	63. 430
Mean, 48. 2546 ± . 001	Mean, 63. 4316 ± . 0032

Hence, Ce = 141.55. Hence Ce = 141.47.

[1] Amer. Journ. Sci. (2), 49, 358. 1870.

[2] Journ. prakt. Chem., 120, 222. 1875.

Robinson's work, published in 1884,[1] was based upon pure cerium chloride, prepared by heating dry cerium oxalate in a stream of dry, gaseous hydrochloric acid. This compound was titrated with standard solutions of pure silver, prepared according to Stas, and these were weighed, not measured. In the third column I give the ratio between $CeCl_3$ and 100 parts of silver:

$CeCl_3$.	*Ag.*	*Ratio.*
5.5361	7.26630	76.189
6.0791	7.98077	76.172
6.4761	8.50626	76.133
6.98825	9.18029	76.122
6.6873	8.78015	76.164
7.0077	9.20156	76.158
6.9600	9.13930	76.150
		Mean, 76.155±.0065

Reduced to a vacuum this becomes 76.167. Hence Ce = 140.13.

In a later paper,[2] Robinson discusses the color of ceric oxide, and criticizes the work of Wolf. He shows that the pure oxide is not white, and makes it appear probable that Wolf's materials were contaminated with compounds of lanthanum. He also urges that Wolf's cerium sulphate could not have been absolutely definite, because of defects in the method by which it was dehydrated.

Brauner,[3] in 1885, investigated cerium sulphate with extreme care, and appears to have obtained material free from all other earths and absolutely homogeneous. The anhydrous salt was calcined with all necessary precautions, and the data obtained, reduced to a vacuum were as follows:

$Ce_2(SO_4)_3$.	*CeO_2.*	*Per cent. CeO_2.*
2.16769	1.31296	60.5693
2.43030	1.47250	60.5707
2.07820	1.25860	60.5620
2.21206	1.33989	60.5721
1.28448	.77845	60.6043
1.95540	1.18436	60.5687
2.46486	1.49290	60.5673
2.04181	1.23733	60.5997
2.17714	1.31878	60.5739
2.09138	1.26654	60.5605
2.21401	1.34139	60.5863
2.44947	1.48367	60.5711
2.22977	1.35073	60.5771
2.73662	1.65699	60.5486
2.62614	1.59050	60.5642
1.67544	1.01470	60.5632
1.57655	.95540	60.6007
2.72882	1.65256	60.5600
2.10455	1.27476	60.5716
2.10735	1.27698	60.5965
2.43557	1.47517	60.5692
3.01369	1.82524	60.5649
4.97694	3.01372	60.5537
		Mean, 60.5729±.0021

Hence, Ce = 140.22.

In 1895 several papers upon the cerite earths were published by Schutzenberger.[4] In the first of these a single determination of atomic weight is given. Pure CeO_2, of a yellowish-white color, was converted into sulphate, which was dried in a current of dry air at 440°. This salt, dissolved in water, was poured into a hot solution of caustic soda, made from sodium, and, after filtration and washing, the filtrate, acidulated with hydrochloric acid, was precipitated

[1] Chemical News, 50, 251. 1884. Proc. Roy. Soc., 37, 150.
[2] Chemical News, 54, 229. 1886.
[3] Sitzungsb. Wien. Akad., Bd. 92. July, 1885.
[4] Compt. Rend., 120, pp. 663, 962, and 1143. 1895.

with barium chloride. The trace of sulphuric acid retained by the cerium hydroxide was recovered by re-solution and a second precipitation and added to the main amount. One hundred parts of $Ce_2(SO_4)_3$ gave 123.30 of $BaSO_4$. Hence, Ce = 139.87.

Schutzenberger, criticizing Brauner's work, claims that the latter was affected by a loss of oxygen during the calcination of the cerium dioxide.

In his second and third papers Schutzenberger describes the results obtained upon the fractional crystallization of cerium sulphate. Preparations were thus made yielding oxides of various colors—canary-yellow, rose, yellowish-rose, reddish and brownish-red. These oxides, by synthesis of sulphates, the barium-sulphate method, etc., gave varying values for the atomic weight of cerium, ranging from 137.7 to 143.3. Schutzenberger therefore infers that cerium oxide from cerite contains small quantities of another earth of lower molecular weight; but the results as given are not conclusive. The third paper is essentially a continuation of the second, with reference to the didymiums.[1]

Schutzenberger's papers were promptly followed by one from Brauner,[2] who claimed priority in the matter of fractionation, and gave some new data, the latter tending to show that cerium oxide is a mixture of at least two earths. One of these, of a dark salmon color, he ascribed to a new element, "meta-cerium." The other he called cerium, and gave for it a preliminary atomic weight determination. The pure oxalate, by Gibbs' method, gave 46.934 per cent of CeO_2, and, on titration with potassium permanganate, 29.503 and 29.506 per cent of C_2O_3. Hence, Ce = 139.81. In mean, this ratio may be written—

$$3C_2O_3 : 2CeO_2 :: 100 : 159.074$$

which will be combined with other corresponding expressions later.

Wyrouboff and Verneuil [3] determined the atomic weight of cerium by analyses of the sulphate $Ce_2(SO_4)_3.8H_2O$. The salt was prepared from three different sources, two samples from monazite and one from cerite. It was dehydrated at 250°, and reduced to CeO_2 at 1,500°. The latter was perfectly white. The weights were as follows:

Hydrous sulphate.	*Anhydrous sulphate.*	*CeO_2.*
1.2385	0.9875	0.5977
1.2730	1.0148	.6138
1.2030	.9590	.5794
1.5420	1.2295	.7430
.9642	.7685	.4642
1.3260	1.0571	.6389
1.1429	.9112	.5512
.9072	.7232	.4372
1.2114	.9658	.5840
1.2411	.9894	.5984

Hence, the following percentages:

H_2O.	*CeO_2 in hydrate.*	*CeO_2 in $Ce_2(SO_4)_3$.*
20.267	48.259	60.526
20.282	48.216	60.484
20.282	48.162	60.417
20.265	48.184	60.431
20.296	48.143	60.403
20.279	48.182	60.438
20.273	48.280	60.557
20.282	48.192	60.453
20.274	48.208	60.468
20.280	48.215	60.481
Mean, 20,278 ± .0019	48.204 ± .0095	60.466 ± .0103
Hence, Ce=139.22	139.39	139.45

[1] Similar results were also obtained by Boudouard (Compt. Rend., 125, 772. 1897). The correctness of these conclusions is questionable.
[2] Chem. News, 71, 283.
[3] Bull. Soc. Chim. (3), 17, 679. 1897. Also Ann. Chim. Phys. (8), 9, 349. Moissan, Compt. Rend., 124, 1233, also describes white ceric oxide.

Kölle [1] studied anhydrous cerium sulphate, which he reduced by calcination to CeO_2. His figures are as follows:

$Ce_2(SO_4)_3$.	CeO_2.	Per cent CeO_2.
1.84760	1.11648	60.429
1.16074	.70078	60.331
1.53599	.92722	60.366
.97196	.58661	60.353
1.40374	.84760	60.384
1.75492	1.05956	60.377
1.53784	.92853	60.379
1.64233	.99150	60.372
		Mean, 60.374±.0067

Hence, Ce = 138.79, an unusually low and improbable value.

The very careful investigation by Brauner and Batěk [2] involved the study of two cerium salts, the sulphate and the oxalate. The sulphate was dehydrated at 440°, and then calcined to oxide. The figures given in the next table represent a number of different samples of the salt, but I have here combined the data into one series:

$Ce_2(SO_4)_3$.	CeO_2.	Per cent. CeO_2.
1.5074	0.9130	60.568
1.7979	1.08945	60.596
1.5937	.9665	60.645
2.6240	1.5895	60.575
1.2161	.7370	60.604
1.5074	.9130	60.568
1.2192	.7386	60.581
		Mean, 60.591±.0070

Reduced to a vacuum this becomes 60.584.

Hence, Ce = 140.30.

Combining this series with others, we have—

Wolf	60.366 ± .0308
Wing	60.244 ± .0308
Brauner	60.5729± .0021
Wyrouboff and Verneuil	60.466 ± .0103
Kölle	60.374 ± .0067
Brauner and Batěk	60.584 ± .0070
General mean	60.5528± .0019

Wing's mean is here arbitrarily given equal weight with that of Wolf, but both series practically vanish.

Cerium oxalate contains water, in proportions which are not absolutely constant; at least not constant enough for good atomic weight determinations. In Buehrig's analyses the water was estimated, but it is doubtful whether the estimations can be made with adequate sharpness. Cerium oxalate, therefore, is best handled by the method of Stolba and Gibbs; which consists in determining the amount of ceric oxide left after calcination; and in another portion of the same sample, estimating the radicle C_2O_3 by titration with potassium permanganate. From the ratio $3C_2O_3 : 2CeO_2$ the atomic weight of cerium can be calculated.

This method was followed by Brauner, in a single determination which has already been cited. It was also adopted by Brauner and Batěk, who give five sets of determinations, with vacuum weights, as follows. I cite now only the percentages of CeO_2 and C_2O_3, as computed from the weighings, together with the required ratio:

Sample I.

Per cent CeO_2.	Per cent C_2O_3.	Ratio.
46.949	29.423	150.503
46.939	29.391	159.685

[1] Beiträge zur Kenntniss des Cers. Inaugural Dissertation, Zürich. 1898.

[2] Zeitsch. anorg. Chem., 34, 103. 1903.

Per cent CeO_2.	*Per cent C_2O_3.*	*Ratio.*
46.913	29.393	159.664
46.920	29.442	159.398
———	29.422	159.507
Mean, 46.930	29.397	159.642
	29.406	159.593
	29.459	159.306
	29.414	159.540
	29.459	150.306
	29.459	159.306
	29.436	159.431

The ratio here is computed from the individual figures for C_2O_3 and the mean for CeO_2.

Sample II.

Per cent CeO_2.	*Per cent C_2O_3.*	*Ratio.*
47.197	29.601	159.353
47.089	29.564	159.552
47.225	29.559	159.579
Mean, 47.170		

Samples III, IV, V.

	Per cent CeO_2.	*Per cent C_2O_3.*	*Ratio.*
III	47.161 47.160	29.512	159.718
IV	46.926 46.922	29.391	159.654
V	47.039	29.531	159.287

The mean of the 18 values for the ratio is 159.501 ±.0285. Hence Ce=140.27.

In a later memoir, Brauner[1] gives additional analyses of cerium oxalate and sulphate. The oxalate figures are as follows:

Per cent CeO_2.	*Per cent C_2O_3.*	*Ratio.*
47.070	29.548	159.304
47.067	29.544	159.325
47.077	29.478	159.682
47.070	29.486	159.638
47.974		Mean, 159.487±.0677
Mean, 47.071		

Hence, Ce=140.26.

If we give to Brauner's earliest, single determination, the weight of one experiment in the Brauner and Batěk series, the values for this ratio combine thus:

Brauner, early	159.074±.0990
Brauner and Batěk	159.501±.0285
Brauner, latest	159.487±.0677
General mean	159.471±.0254

In the memoir last cited Brauner also gives a series of determinations based on the calcination of the octohydrated cerium sulphate. In the subjoined table I include two separate determinations given near the beginning of the paper. All weights were reduced to a vacuum standard:

Sulphate.	*CeO_2.*	*Per cent CeO_2.*
1.98989	0.96175	48.332
1.99154	.96251	48.330
2.33919	1.13027	48.319
1.95882	.94679	48.335
1.20961	.58453	48.324
1.54162	.74048	48.329
1.67748	.81074	48.331
2.02736	.97985	48.331
		Mean, 48.329±.0011

[1] Zeitsch. anorg. Chem., 34, 207. 1903.

Brauner rejects the third determination, a procedure which changes the mean to 48.330 ± .0009. We may adopt the latter and combine it with another series, thus:

Wyrouboff and Verneuil	48.204 ± .0095
Brauner	48.330 ± .0009
General mean	48.329 ± .0009

From Brauner's series Ce = 140.26.

Brauner discusses at some length the color of ceric oxide, and describes it as nearly white, but with a faint tinge of brownish-yellow.

The ratios, good and bad, for cerium now are—

(1) Percentage CeO_2 from $Ce_2(SO_4)_3$, 60.5528 ± .0019.
(2) Percentage CeO_2 in $Ce_2(SO_4)_3 8H_2O$, 48.329 ± .0009
(3) Percentage H_2O in $Ce_2(SO_4)_3.8H_2O$, 20.278 ± .0019
(4) Percentage CeO_2 from $Ce_2(C_2O_4)_3$. 63.4316 ± .0032
(5) Percentage CO_2 from $Ce_2(C_2O_4)_3$, 48.2546 ± .001
(6) $3Ag : CeCl_3 :: 100 : 76.167 \pm .0065$.
(7) $3C_2O_3 : 2CeO_2 :: 100 : 159.471 \pm .0254$

The antecedent atomic weights are—

Ag = 107.880 ± .00016	S = 32.065 ± .00012
Cl = 35.4605 ± .0001	C = 12.0025 ± .00019
H = 1.0078 ± .0001	

Hence,

From ratio—	
3	Ce = 139.212 ± .0276
1	140.078 ± .0088
6	140.127 ± .0210
7	140.240 ± .0275
2	140.249 ± .0044
4	141.473 ± .0166
5	141.559 ± .0041
Hence	Ce = 140.841 ± .0027

This mean appears to be, on chemical grounds, too high; because of the evident overweighting of ratio 5. If we reject the aberrant values, given by ratios 3, 4, and 5, the general mean of the remaining values is

Ce = 140.214 ± .0038.

This represents mainly the work of Brauner and Robinson.

PRASEODYMIUM.

In 1885 Auer von Welsbach [1] succeeded in proving that the old "didymia" was a mixture of two earths, one yielding green and the other rose-colored salts. To the corresponding metals, praseodymium and neodymium, he assigned the atomic weights Pr = 143.6 and Nd = 140.8, respectively, values which were curiously reversed, either in printing or by the error of a copyist. The true values are now known to be nearly Pr = 141 and Nd = 144, in round numbers. For "didymium," many discordant atomic weight determinations had been made, which now have only historical interest, and need therefore no consideration now. They are thoroughly summed up in the first edition of this work, which was published about three years before Welsbach's brilliant discovery.

In 1898 Brauner [2] published a preliminary notice upon praseodymium. Thirteen determinations of the atomic weight, by both the sulphate and the oxalate methods, gave values from 140.84 to 141.19, in mean 140.95, but the details of the work were not given. These early data, therefore, are not now available for discussion. The first fully described series of determinations was made by Jones,[3] who published his results a little later than Brauner.

[1] Monatsh. Chem., 6, 477. 1885. [2] Proc. Chem. Soc., 14, 70. 1898. [3] Amer. Chem. Journ., 20, 345. 1898.

Jones effected the synthesis of praseodymium sulphate from the oxide, the latter having been first reduced from Pr_4O_7 to Pr_2O_3 by heating in hydrogen. The material, after purification, still contained minute traces of lanthanum and neodymium, but these were too small to seriously affect the atomic weight determination. The weights and percentages appear in the following table:

Pr_2O_3.	$Pr_2(SO_4)_3$.	Per cent Pr_2O_3.
0.5250	0.9085	57.789
.6436	1.1135	57.800
.7967	1.3788	57.782
.7522	1.3018	57.782
.7788	1.3473	57.805
.6458	1.1172	57.805
.6972	1.2062	57.801
.7204	1.2464	57.798
.8665	1.4990	57.805
.6717	1.1624	57.796
.7439	1.2873	57.788
.6487	1.1224	57.796
		Mean, 57.796±.0016

Hence, Pr = 140.46.

C von Schéele,[1] also in 1898, gave three series of determinations. First, by the synthesis of praseodymium sulphate, which, however, contained a little lanthanum sulphate, as follows:

Pr_2O_3.	$Pr_2(SO_4)_3$.	Per cent Pr_2O_3.
1.6738	2.8926	57.865
1.4327	2.4788	57.798
1.1105	1.9221	57.775
1.0072	1.7431	57.782
		Mean, 57.805±.0139

Hence, Pr = 140.53.

The second series by von Schéele is somewhat obscure, being a combination of the oxalate and sulphate methods. A part of the oxalate was converted into sulphate, and in another part the C_2O_3 radicle was determined by titration with permanganate solution. The proportion of oxide in sulphate was also found. I give below the several percentages, and also the ratio $3C_2O_3 : Pr_2(SO_4)_3$:

Sulphate from oxalate.	Per cent C_2O_3.	Pr_2O_3 in sulphate.	Ratio.
81.682	31.07	57.73	
81.638	31.06	57.71	
	31.11		
Mean, 81.665			
	Mean, 31.08		262.515
77.828	29.60	57.77	262.845
	29.58		
	29.64		
	Mean, 29.61	57.737	262.680
		±.0117	±.1113
		Pr=140.06	139.62

These two series have small claims to consideration, and may be regarded as preliminary. The third series, by the sulphate method, is far better:

Pr_2O_3.	$Pr_2(SO_4)_3$.	Per cent Pr_2O_3.
0.6872	1.1890	57.796
.7834	1.3550	57.815
.6510	1.1260	57.815
.7640	1.3216	57.809
.5183	.8967	57.801
		Mean, 57.807±.0026

Hence, Pr = 140.54

[1] Zeitsch. anorg. Chem., 17, 310. 1898.

In 1901 Brauner [1] gave a preliminary notice of an investigation upon the atomic weight of praseodymium, but without details. He has since published his data in Abegg's Handbuch der anorganischen Chemie,[2] as follows:

First, the octohydrated sulphate was dehydrated at 500°, then calcined to oxide, and the latter finally analyzed iodometrically to determine the true proportions of Pr_2O_3. Percentage A in the next table is that of Pr_2O_3 in the hydrous sulphate, and B refers to the anhydrous salt:

$Pr_2(SO_4)_3.8H_2O$.	$Pr_2(SO_3)_4$.	Pr_2O_3.	*Per cent A.*	*Per cent B.*
1.29269	1.03242	0.59747	46.219	57.871
1.27990	1.02193	.59137	46.204	57.868
			Mean, 46.211	57.8695
			±.0050	
			Pr= 141.09	

Secondly, four samples of praseodymium oxalate were analyzed by the method already described under cerium and lanthanum. I give the ratio computed from the percentages, in the form $3C_2O_3 : Pr_2O_3 : : 100 : x$:

Sample.	*Per cent* Pr_2O_3.	*Per cent* C_2O_3.	*Ratio.*	*Weight.*
A	45.183	29.581 29.581	152.743	2
B	45.142 45.098 45.095 45.102 45.063	29.499 29.593 29.532 29.511	152.671	4
C	45.032 45.123	29.503 29.483	152.840	2
D	45.136	29.565 29.562	152.677	2

Each value for the ratio is here weighted according to the number of the C_2O_3 determinations. The means of all, thus weighted, is 152.720 ±.0148.

Hence, Pr=140.95.

Finally, Brauner affected the synthesis of the anhydrous sulphate. Praseodymium oxalate was calcined, and the composition of the oxide produced was ascertained by iodometric titration. It was then converted into sulphate, with the correction, described under lanthanum, for excess of sulphuric acid. The corrected data are these:

Pr_2O_3.	$Pr_2(SO_4)_3$.	*Per cent* Pr_2O_3.
0.73359	1.26782	57.863
.64871	1.12059	57.890
.74103	1.28051	57.870
,72894	1.25972	57.865
.36559	.63350	57.867
.82769	1.43024	57.871

In his first series Brauner found, for the same percentage, 57.871 and 57.868. Including these, the eight determinations, taken as one series, give a mean of 57.871±.0021.

Hence, Pr=140.97.

Combining this means with other means for the same ratio we have—

Jones	57.796 ±.0016
Schéele, first	57.805 ±.0139
Schéele, second	57.737 ±.0117
Schéele, third	57.807 ±.0026
Brauner	57.871 ±.0021
General mean	57.8194±.0010

Three other determinations by Welsbach[3] were published in 1903. He used the sulphate method and found Pr=140.64, 140.50, and 140.56 when O=16. Unfortunately, he gave no

[1] Proc. Chem. Soc., 17, 65. [2] Bd. 3, Abth. 1, pp. 263–265. [3] Sitzungsb. Wien Akad., 112, 1037. 1903.

weighings, nor did he state what value he used for the atomic weight of sulphur. His figures, therefore, are unavailable for discussion now.

Three determinations by Feit and Przibylla,[1] who used the peculiar volumetric method already described under lanthanum, are as follows:

Pr_2O_3.	O.	Atomic weight.
0.54010	0.07879	140.518
.53420	.07789	140.601
.50054	.07302	140.516
		Mean, 140.545±.0189

The most extensive and thorough determinations of the atomic weight of praseodymium are by Baxter and Stewart,[2] who analyzed the chloride by the standard methods. Two series of figures are given, representing the two usual ratios, with the following results. All weights are reduced to a vacuum:

Series 1.

$PrCl_3$.	Ag.	Ratio.
7.66554	10.03129	76.4163
8.78959	11.50311	76.4106
5.01155	6.55898	76.4075
6.04235	7.90820	76.4061
6.14745	8.04563	76.4073
6.32550	8.27866	76.4054
5.12982	6.71359	76.4095
4.59463	6.01331	76.4077
4.77556	6.24994	76.4097
5.96661	7.80908	76.4060
6.87536	8.99824	76.4079
5.73602	7.50707	76.4082
4.64585	6.08029	76.4084
6.85492	8.97148	76.4079
8.01311	10.49250	76.4080
6.17045	8.07425	76.4214
6.90040	9.03064	76.4110
7.08498	9.27274	76.4065
5.81310	7.60811	76.4066
6.20845	8.12541	76.4079
7.07590	9.26045	76.4099
5.77646	7.56000	76.4082
5.72002	7.48596	76.4100
		Mean, 76.4090±.0006

Hence, Pr = 140.909.

Series 2.

$PrCl_3$.	AgCl.	Ratio.
4.12848	7.17915	57.5065
6.01605	12.02533	57.5123
7.66554	13.32931	57.5089
5.01155	8.71379	57.5128
6.04235	10.50744	57.5054
6.14745	10.69050	57.5039
6.32550	10.99855	57.5121
4.59463	7.98940	57.5090
5.96661	10.37554	57.5065
6.87536	11.95508	57.5100
4.64585	8.07758	57.5154
6.85492	11.91774	57.5186
8.01711	13.93953	57.5135
6.17045	10.72833	57.5155
6.90040	11.99946	57.5059
7.08498	12.32019	57.5071

[1] Zeitschr. anorg. Chem., 50, 258. 1906.

[2] Journ. Amer. Chem. Soc., 37, 516. 1915.

$PrCl_3$.	$AgCl$.	Ratio.
6.20845	10.79552	57.5095
7.07590	12.30401	57.5089
5.77646	10.04403	57.5113
5.72002	9.94651	57.5078
		Mean, 57.5100±.0007

Hence, Pr = 140.924.

The ratios for praseodymium now are—

(1) $Pr_2(SO_4)_3.8H_2O : Pr_2O_3 :: 100 : 46.211 \pm .0050$.
(2) $Pr_2(SO_4)_3 : Pr_2O_3 :: 100 : 57.8194 \pm .0010$.
(3) $3C_2O_3 : Pr_2(SO_4)_3 :: 100 : 262.680 \pm .1113$.
(4) $3C_2O_3 : Pr_2O_3 :: 100 : 152.720 \pm .0148$.
(5) $O : Pr :: 16 : 140.545 \pm .0189$.
(6) $3Ag : PrCl_3 :: 100 : 76.4090 \pm .0006$.
(7) $3AgCl : PrCl_3 :: 100 : 57.5100 \pm .0007$.

To reduce these ratios we have—

Ag=107.880 ±.00016 S=32.065 ±.00012
Cl= 35.4605±.00011 C=12.0025±.00019
H=1.0078±.0001

Hence,

From ratio—	
3	Pr=139.616±.1200
5	140.545±.0189
2	140.624±.0048
7	140.909±.0022
6	140.924±.0032
4	140.949±.0160
1	141.088±.0235
General mean	Pr=140.876±.0017

This means is a little lower than the values found by Baxter and Stewart, and the latest determinations by Brauner. The work of Jones, however, should not be entirely rejected. The rounded off value 140.9 is probably near the truth.

NEODYMIUM.

Our knowledge of the atomic weight of neodymium is almost entirely based upon studies of the sulphate and the chloride. Welsbach's first determination was cited under praseodymium, and needs no further consideration. So also Brauner's[1] first preliminary figure Nd = 143.63, given without analytical details, may be dismissed here. The first important series of determinations is that by Jones,[2] published in 1898. The synthesis of the sulphate was effected in the usual way, with the following results:

Nd_2O_3	$Nd_2(SO_4)_3$	Per cent Nd_2O_3
0.8910	1.5296	58.251
.7880	1.3530	58.241
.9034	1.5509	58.250
.7668	1.3166	58.241
.8908	1.5296	58.237
.8848	1.5194	58.234
.8681	1.4903	58.250
.8216	1.4103	58.257
.8531	1.4646	58.248
.8711	1.4957	58.240
.8932	1.5332	58.257
.8893	1.5268	58.246
		Mean, 58.246±.0015

Hence, Nd = 143.53.

[1] Proc. Chem. Soc., 14, 72. 1898. [2] Amer. Chem. Journ., 20, 345. 1898. See additional note in Zeitsch. anorg. Chem., 19, 339. 1899.

One determination, by Boudouard,[1] was made by calcination of the sulphate. 2.758 grammes of $Nd_2(SO_4)_3$ gave 1.605 of Nd_2O_3, or 58.194 per cent. Hence, Nd = 143.18.

Brill,[2] in 1905, made two analyses of neodymium sulphate, with the aid of the microbalance. His percentages of Nd_2O_3 are—

58.000
58.180
Mean, 58.090 ± .0600

Hence, Nd = 142.45.

In Abegg's Handbuch, Brauner[3] gives the details of a synthesis of neodymium sulphate, with corrections for excess of acid. 0.93788 gramme Nd_2O_3 gave 1.60873 $Nd_2(SO_4)_3$. Per cent Nd_2O_3, 58.299, whence Nd = 143.90.

Holmberg,[4] who employed the usual synthetic method, found no serious difficulty in obtaining a neutral sulphate. In his series of determinations, therefore, a correction for excess of sulphuric acid was not needed. His six syntheses are as follows:

Nd_2O_3	*$Nd_2(SO_4)_3$*	*Per cent Nd_2O_3*
0.9692	1.6618	58.322
.6584	1.1287	58.333
1.0292	1.7643	58.335
1.0118	1.7346	58.330
.5518	.9462	58.317
.5345	.9164	58.326
		Mean, 58.327 ± .0019

Hence, Nd = 144.09.

In combining these various determinations of the oxide-sulphate ratio, the single experiments by Boudouard and Brauner are each given the probable error of one experiment in Jones's series:

Jones	58.246 ± .0015
Boudouard	58.194 ± .0067
Brill	58.090 ± .0600
Brauner	58.299 ± .0067
Holmberg	58.327 ± .0019
General mean	58.2831 ± .0011

In this combination only the series by Jones and Holmberg are important. The other figures count for little or nothing. Welsbach's[5] determinations, also by the sulphate method, cannot be safely utilized, for lack of details. He found Nd = 144.55, 144.52, and 144.57; in mean, 144.547 ± .0103.

Feit and Przibylla[6] give the following data for neodymium, obtained by their volumetric method:

Nd_2O_3	*O.*	*Atomic weight*
0.5380	0.07661	144.542
.5388	.07675	144.485
.5358	.07632	144.491
.5265	.07497	144.547
		Mean, 144.516 ± .0111

The determinations of the atomic weight of neodymium by Baxter and Chapin[7] are based upon analyses of the chloride by the usual standard methods. Their data, with vacuum weights, are as follows:

$NdCl_3$.	*Ag.*	*AgCl.*	*Ag ratio.*	*AgCl ratio.*
3.16218	.....	5.42546	.....	58.2841
2.93305	.....	5.03226	.....	58.2850

[1] Comp. Rend., 126, 900. 1898.
[2] Zeitsch. anorg. Chem., 47, 464. 1905.
[3] Abegg's Handbuch, Bd. 3, Abth. 1, p. 276. Preliminary note in Proc. Chem. Soc., 17, 66. 1901.
[4] Zeitsch. anorg. Chem., 53, 124. 1907.
[5] Sitzungsb. Wien Akad., 112, 1037. 1903.
[6] Zeitsch. anorg. Chem., 50, 259. 1906. For the process, see under lanthanum.
[7] Proc. Amer. Acad., 46, 215. 1910.

$NdCl_3$.	Ag.	AgCl.	Ag ratio.	AgCl ratio.
2.99149	.....	5.13195	.....	58.2915
2.62468	.....	4.50338	.....	58.2825
2.38439	.....	4.09064	.....	58.2889
2.55827	.....	4.38591	.....	58.2894
3.59114	.....	6.16095	.....	58.2887
4.27402	5.18555	7.33203	77.4482	58.2925
4.69459	.....	8.05444	.....	58.2857
2.79574	3.61030	4.79630	77.4379	58.2895
2.59810	.....	4.45741	.....	58.2872
3.42064	4.41695	5.86872	77.4435	58.2860
4.11855	5.31786	7.06518	77.4475	58.2936
3.95958	5.11289	6.79345	77.4431	58.2853
2.71834	.....	4.66395	.....	58.2841
2.77391	3.58196	.....	77.4379	.....
4.64435	5.99699	.....	77.4447	.....
			Mean, $\overline{77.4437}\pm.0009$	$\overline{58.2876}\pm.0006$

From the Ag ratio Nd = 144. 258.

From the AgCl ratio Nd = 144.268.

Similar determinations are due to Baxter, Whitcomb, and Stewart,[1] whose data are as follows:

$NdCl_3$.	Ag.	AgCl.	Ag ratio.	AgCl ratio.
3.34038	4.31287	.....	77.4514	.....
4.03869	5.21445	6.92786	77.4519	58.2963
4.48251	5.78760	7.69005	77.4503	58.2897
3.75204	4.84458	6.43738	77.4482	58.2852
6.00909	7.75892	10.30876	77.4475	58.2911
4.96466	6.41045	8.51634	77.4464	58.2957
4.15431	5.36392	7.12743	77.4492	58.2862
5.53210	7.14338	9.49134	77.4437	58.2858
4.73995	6.12054	8.13232	77.4433	58.2853
4.22430	5.45444	7.24714	77.4470	58.2892
5.93271	7.66088	10.17891	77.4416	58.2844
5.60324	7.23524	9.61299	77.4439	58.2883
7.22817	9.33359	12.40098	77.4426	58.2871
5.16230	6.66603	8.86147	77.4419	*58.2556
4.50348	5.81558	7.72718	*77.4382	58.2810
6.42333	8.29438	11.02284	77.4419	*58.2729
7.59834	9.80822	.....	*77.4385	.....
			Mean, $\overline{77.4461}\pm.0006$	$\overline{58.2881}\pm.0008$

The starred determinations are rejected by the authors.

From the Ag ratio, Nd = 144.266.

From the AgCl ratio, Nd = 144.270.

Combining both sets of analyses, namely, of Baxter and Chapin and Baxter, Whitcomb and Stewart we have—

$$3Ag : NdCl_3 :: 100 : 77.4449 \pm .0005$$
$$3AgCl : NaCl_3 :: 100 : 58.2878 \pm .0005$$

There are now four ratios for neodymium. Reducing them with

$$Ag = 107.880 \pm .00016$$
$$Cl = 35.4605 \pm .00011$$
$$S = 32.0650 \pm .00012$$

we have—

From the sulphate	Nd = 143.790 ± .0054
From the silver ratio	144.262 ± .0017
From the silver chloride ratio	144.269 ± .0022
From the oxide	144.514 ± .0111
General mean	Nd = $\overline{144.242 \pm .0013}$

This final value is essentially that found by Baxter and his colleagues.

[1] Journ. Amer. Chem. Soc., 38, 302. 1916.

SAMARIUM.

According to Marignac,[1] the atomic weight of samarium is 149.4. He gives, however, one analysis of the octohydrated sulphate, as follows: 1.8515 grammes gave 0.365 of water, and on calcination lost 0.607 SO_3. Hence, the percentage of Sa_2O_3 in the hydrous salt is 47.502, and in the anhydrous sulphate 59.166. From these data Sa = 149.87 and 150.01. The first regular series of atomic-weight determinations was by Cleve,[2] who effected the synthesis of the sulphate from the oxide. Data as follows:

Sa_2O_3.	$Sa_2(SO_4)_3$.	Per cent Sa_2O_3.
1.6735	2.8278	59.180
1.9706	3.3301	59.175
1.1122	1.8787	59.201
1.0634	1.7966	59.190
.8547	1.4440	59.190
.7447	1.2583	59.183
		Mean, 59.1865±.0025

Hence, Sa = 150.16.

Another set of determinations by Bettendorff,[3] after the same general method, gave as follows:

Sa_2O_3.	$Sa_2(SO_4)_3$.	Per cent Sa_2O_3.
1.0467	1.7675	59.219
1.0555	1.7818	59.238
1.0195	1.7210	59.225
		Mean, 59.227±.0038

Hence, Sa = 150.45.

In a single analysis of the hydrous sulphate, Brauner[4] obtained the following figures: 1.36567 grammes $Sa_2(SO_4)_3.8H_2O$ gave 1.09770 $Sa_2(SO_4)_3$ and 0.65046 Sa_2O_3. Per cent Sa_2O_3 in hydrate, 47.629; in anhydrous salt, 59.257. Hence, Sa = 150.76 and 150.67.

Käppel,[5] cited by Muthmann and Weiss, from 4.12673 grammes $Sa_2(SO_4)_3$ obtained 2.45028 Sa_2O_3, or 59.376 per cent. Hence, Sa = 151.53.

Brill's[6] analyses of samarium sulphate, with the aid of the microbalance, need not be considered, for his two experiments, as recorded, are widely discordant. The most thorough investigation by the sulphate method is that by Urbain and Lacombe,[7] whose material was scrupulously freed from other rare earths, an impurity to be discussed more fully a little later. The samarium preparations of Urbain and Lacombe were derived from different sources, gadolinite, monazite sand, etc., and the octohydrated sulphate was analyzed by dehydration and calcination in the ordinary way. In the next table I give their weights, and also three percentage columns, as follows: A, percentage of $Sa_2(SO_4)_3$, in $Sa_2(SO_4)_3.8H_2O$. B, Sa_2O_3 in the hydrous sulphate. C, Sa_2O_3 in the anhydrous sulphate.

$Sa_2(SO_4)_3.8H_2O$.	$Sa_2(SO_4)_3$.	Sa_2O_3.	A.	B.	C.
1.0499	0.8435	0.4996	80.341	47.585	59.229
1.2898	1.0362	.6137	80.338	47.580	59.225
1.3650	1.0969	.6497	80.359	47.597	59.230
1.7992	1.4453	.8557	80.330	47.560	59.206
1.8636	1.4977	.8873	80.366	47.605	59.244
.8407	.6749	.4001	80.277	47.591	59.283
2.5107	2.0172	1.1948	80.344	47.588	59.228
3.1171	2.5045	1.4840	80.347	47.608	59.253
2.9425	2.3635	1.4004	80.323	47.592	59.251

[1] Arch. Sci. Phys. Nat. (3), 3, 435. 1880. Oeuvres Complètes, 2, 709.
[2] Journ. Chem. Soc., 43, 302. 1883.
[3] Amer. Chem. Pharm., 263, 164. 1891
[4] Abegg's Handbuch, Bd. 3, Abth. 1, p. 284. Preliminary notice in Journ. Chem. Soc., 43, 287. 1883.
[5] Liebig's Annalen, 331, 16. 1904.
[6] Zeitsch. anorg. Chem., 47, 464. 1905.
[7] Compt. Rend., 138, 1166. 1904.

$Sa_2(SO_4)_3.8H_2O$.	$Sa_2(SO_4)_3$.	Sa_2O_3.	*A.*	*B.*	*C.*
3.2200	2.5872	1.5324	80.348	47.590	59.230
2.8382	2.2804	1.3508	80.347	47.594	59.237
			Mean, 80.338	47.590	59.238
			±.0048	±.0026	±.0040

From A, Sa = 150.35.
From B, Sa = 150.49.
From C, Sa = 150.53.

Two of the ratios given by Urbain and Lacombe's experiments may now be combined with former series of determinations. First, for the percentage of Sa_2O_3 in the anhydrous sulphate, giving the single determinations of Marignac, Brauner, and Käppel each the weight of one experiment in Urbain and Lacombe's series:

Marignac	59.166 ±.0199
Cleve	59.1865±.0025
Bettendorff	59.227 ±.0038
Brauner	59.257 ±.0199
Käppel	59.376 ±.0199
Urbain and Lacombe	59.238 ±.0040
General mean	59.2074±.0018

Secondly, for the percentage of Sa_2O_3 in the hydrous sulphate, giving, arbitrarily, the single determinations of Marignac and Brauner the same weight as in the anhydrous series:

Marignac	47.502±.0199
Brauner	47.629±.0199
Urbain and Lacombe	47.590±.0026
General mean	47.589±.0025

The value of these combinations is perhaps questionable. The earlier work on the atomic weight of samarium is affected by the discovery of europium, which was made by Demarcay.[1] According to this chemist, the original samaria contained admixtures of europia, which tended to raise its apparent molecular weight. For samarium itself, by the sulphate method, he found Sa = 147.2 to 148, and for europium, Eu = 151. The material studied by Urbain and Lacombe, however, was free from europium, and still gave a higher percentage of oxide in sulphate than the substances examined by the earlier investigators. Their material, therefore, was either free from europium, or else contained compensating impurities. At all events, the general means are close to Urbain and Lacombe's figures, and may be allowed to stand unchanged.

Still another method for measuring the atomic weight of samarium has been proposed by Matignon,[2] who found that the normal sulphate, heated to between 500° and 1000°, yielded a stable basic salt, Sa_2SO_6. In one determination, 0.7325 gramme $Sa_2(SO_4)_3$ gave 0.5335 of Sa_2SO_6. Hence Sa = 150.67.

The determinations by Feit and Przibylla,[3] with their special volumetric method, are as follows:

Sa_2O_3.	*O.*	*Atomic weight.*
0.5576	0.07668	150.522
.5576	.07670	150.477
.5583	.07684	150.378
.5633	.07747	150.514
		Mean, 150.473±.0221

More recent determinations of the atomic weight of samarium are by Stewart and James,[4] who analyzed the chloride. Two series of determinations, with vacuum weights, are given, as follows:

[1] Compt. Rend., 122, 728. 1900. Ibid., 130, 1185, 1469. Ibid., 132, 1484.
[2] Compt. Rend., 141, 1230.
[3] Zeitsch. anorg. Chem., 50, 259. 1906.
[4] Journ. Amer. Chem. Soc., 39, 2605. 1917.

Series 1.

$SaCl_3$.	*Ag.*	*Ratio.*
4.05609	5.10860	79.3973
3.00065	3.78044	79.3730
5.28891	6.66424	79.3625
3.75782	4.73748	79.3211
4.76695	6.00873	79.3337
2.97764	3.75234	79.3542
3.82407	4.81761	79.3769
4.47775	5.64365	79.3414
3.33781	4.20712	79.3374
		Mean, 79.3553±.0055

Hence, Sa = 150.444.

Series 2.

$SaCl_3$	*Ag.*	*Ratio.*
4.65174	5.86128	79.3639
5.13023	6.46577	79.3445
4.52826	5.70727	79.3420
6.65425	8.38628	79.3469
6.02908	7.59669	79.3628
5.09858	6.42520	79.3528
4.68220	5.90111	79.3444
4.32763	4.5551	79.3258
		Mean, 79.3479±.0029

Hence, Sa = 150.422.

The general mean of the two series combined is 79.3497 ± .0026.

In all there are six ratios relative to the atomic weight of samarium:

(1) $Sa_2(SO_4)_3.8H_2O : Sa_2(SO_4)_3 : : 100 : 80.338 \pm .0048$
(2) $Sa_2(SO_4)_3.8H_2O : Sa_2O_3 : : 100 : 47.589 \pm .0025$
(3) $Sa_2(SO_4)_3 : Sa_2O_3 : : 100 : 59.2074 \pm .0018$
(4) $Sa_2(SO_4)_3 : Sa_2SO_6 : : 100 : 72.883$
(5) O : Sa : : 16 : 150.473±.0221
(6) $3Ag : SaCl_3 : : 100 : 79.3497 \pm .0026$

To reduce these we have—

Ag = 107.880 ±.00016	S = 32.0650±.00012
Cl = 35.4605 ±.00011	H = 1.0078±.00001

Hence, giving to ratio 4 the arbitrary weight represented by ±.0075:

From ratio—	
3	Sa = 150.312±.0095
1	150.346±.0720
6	150.426±.0085
5	150.473±.0221
2	150.481±.0124
4	150.666±.0750
General mean	Sa = 150.403±.0054

This mean may be a little too low, but it is near that which is derived from the work of Stewart and James.

ADDENDUM.

Since the manuscript of this volume was sent to the printer Owens, Balke, and Kremers[1] have published important work on the atomic weight of samarium. By analyses of the anhydrous chloride they obtained the following results:

[1] Journ. Amer. Chem. Soc., 42, 515. 1920.

$SaCl_3$.	Ag.	At.wt.Sa.	
6.47502	8.15810	150.49	
4.03877	5.08083	150.90	Rejected.
4.25295	5.35928	150.45	
4.34537	5.47663	150.41	
3.84046	4.84002	150.42	
3.32317	4.18820	150.42	
2.96369	3.73504	150.42	
3.34818	4.21936	150.44	
3.27999	4.13333	150.44	
3.00394	5.78769	150.40	
2.36481	2.97970	150.47	
3.68616	4.64577	150.41	
3.17435	4.00020	150.44	
2.81639	3.54932	150.43	
3.13555	3.95155	150.43	
2.91019	3.66744	150.44	
4.15775	5.23973	150.43	
3.32505	4.18972	150.47	
2.06632	62950	150.41	
		Mean, 150.43	

All weights reduced to a vacuum. Determination No. 2 rejected because of impurity in the $SaCl_3$. The determinations by Stewart and James are completely confirmed.

EUROPIUM.

Demarçay,[1] the discoverer of europium, found for its atomic weight the approximate number 151. The first detailed determinations, however, were those of Urbain and Lacombe,[2] who analyzed the octohydrated sulphate. I give their weights, and three percentage columns, as follows: A, $Eu_2(SO_4)_3$ in $Eu_2(SO_4)_3.8H_2O$. B, Eu_2O_3 in $Eu_2(SO_4)_3.8H_2O$. C, Eu_2O_3 in $Eu_2(SO_4)_3$.

$Eu_2(SO_4)_3.8H_2O$.	$Eu_2(SO_4)_3$.	Eu_2O_3.	A.	B.	C.
1.7787	1.4303	0.8500	80.413	47.788	59.428
2.4785	1.9935	1.1848	80.432	47.803	59.433
2.4177	1.9449	1.1554	80.444	47.789	59.407
2.4831	1.9968	1.1870	80.416	47.803	59.445
2.2988	1.8488	1.0990	80.425	47.807	59.444
		Mean,	80.426	47.798	59.431
			±.0038	±.0027	±.0047
		Hence, Eu=	151.99	151.97	151.93

Jantsch [3] determined the atomic weight of europium by calcination of the hydrous sulphate:

Sulphate.	Eu_2O_3.	Per cent Eu_2O_3.
1.3501	0.6455	47.811
1.5054	.7197	47.808
1.5213	.7274	47.814
1.2881	.6159	47.815
		Mean, 47.812 ±.0010

Hence, Eu = 152.05.

Urbain and Lacombe, for the same ratio, found 47.798 ± .0027. The two series combined give 47.810 ± .00094.

Feit and Przibylla [4] have also applied their volumetric method to the determination of this atomic weight, with the following results:

Eu_2O_3.	O.	Atomic weight.
0.3961	0.05385	152.535
.4096	.05566	152.615
.4115	.05594	152.546
		Mean, 152.565 ±.0170

[1] Compt. Rend., 132, 1484. 1900.
[2] Compt. Rend., 138, 627. 1904.
[3] Compt. Rend., 146, 473. 1908.
[4] Zeitsch. anorg. Chem., 50, 260. 1906.

The four ratios for Eu now are—

(1) $Eu_2(SO_4)_3.8H_2O : Eu_2(SO_4)_3 :: 100 : 80.426 \pm .0038$
(2) $Eu_2(SO_4)_3.8H_2O : Eu_2O_3 :: 100 : 47.810 \pm .00094$
(3) $Eu_2(SO_4)_3 : Eu_2O_3 :: 100 : 59.431 \pm .0047$
(4) $O : Eu :: 16 : 152.565 \pm .0170$

Reducing these ratios with $S = 32.0650 \pm .00012$ and $H = 1.0078 \pm .00001$ we have:

From ratio—	
3	Eu=151.935±.0247
1	151.997±.0542
2	152.033±.0048
4	152.565±.0170
General mean	Eu=152.066±.0044

In round numbers the atomic weight of europium is 152.

GADOLINIUM.

Marignac,[1] the discoverer of gadolinium, assigned to its oxide the "equivalent" 120.5, whence, Gd=156.75. Boisbaudran[2] found Gd=155.33, 156.06, 155.76, and 156.12, with preference for the last figure. Cleve, quoted by Boisbaudran, found Gd=154.15, 155.28, 155.1, and 154.77. For these determinations there are no details, and all, probably, are referred to $SO_3 = 80$.

The first chemist to publish his determinations with individual data was Bettendorff.[3] He effected the synthesis of the sulphate from the oxide, and his weights were as follows. The percentage of Gd_2O_3 in $Gd_2(SO_4)_3$ is given in the third column:

Gd_2O_3.	*$Gd_2(SO_4)_3$.*	*Per cent Gd_2O_3.*
1.0682	1.7779	60.082
1.0580	1.7611	60.076
1.0796	1.7969	60.081
		Mean, 60.080±.0013

Hence, Gd=156.75.

Benedicks'[4] series of determinations were also by the synthetic process, as follows:

Gd_2O_3.	*$Gd_2(SO_4)_3$.*	*Per cent Gd_2O_3.*
0.4308	0.7171	60.075
.5675	.9451	60.047
.5726	.9534	60.059
.6785	1.1301	60.039
.7399	1.2329	60.013
1.3253	2.2063	60.069
		Mean, 60.050±.0020

Hence, Gd=156.52.

The two determinations by Marc[5] are unimportant, but cannot be overlooked. The data are—

Gd_2O_3.	*$Gd_2(SO_4)_3$.*	*Per cent Gd_2O_3.*
0.2201	0.3666	60.014
.2444	.4070	60.049
		Mean, 60.032±.0120

Hence, Gd=156.39.

Brauner,[6] in a single experiment, found 0.88884 $Gd_2O_3 = 1.48257$ $Gd_2(SO_4)_3 = 1.83903$ $Gd_2(SO_4)_3.8H_2O$. Per cent Gd_2O_3 in hydrous sulphate, 48.332; in anhydrous salt, 59.951. Hence Gd=155.753 and 155.78.

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[1] Oeuvres Complètes, 2, 704.
[2] Compt. Rend., 111, 409. 1890.
[3] Ann. Chem. Pharm., 270, 376. 1892.
[4] Zeitsch. anorg. Chem., 22, 393. 1899.
[5] Zeitsch. anorg. Chem., 38, 121. 1904.
[6] Abegg's Handbuch, Bd. 3, Abth. 1, p. 304.

The material studied by Brauner was received from Cleve, and was not perfectly pure. The atomic weight found is too low. In combining the figures for the percentage of Gd_2O_3 in $Gd_2(SO_4)_3$, Brauner's determination may be given equal weight with that of Marc. We have then—

Bettendorff	60.080±.0013
Benedicks	60.050±.0020
Marc	60.032±.0120
Brauner	59.951±.0120
General mean	60.070±.0011

The purest gadolinium preparations were probably those studied by Urbain,[1] who calcined the octohydrated sulphate to oxide. Two series of determinations are given, representing different groups of fractions obtained in the purification of his material. The data are as follows:

Series I.

$Gd_2(SO_4)_3.8H_2O$.	Gd_2O_3.	Per cent Gd_2O_3.
1.9256	0.9350	48.557
1.9749	.9589	48.555
1.9975	.9698	48.551
2.1083	1.0231	48.528
1.8993	.9214	48.514
2.2065	1.0707	48.525
1.9535	.9479	48.524
2.2008	1.0685	48.551
2.2482	1.0914	48.546
2.1932	1.0646	48.541
		Mean, 48.539±.0033

Series II.

$Gd_2(SO_4)_3.8H_2O$.	Gd_2O_3.	Per cent Gd_2O_3.
2.0551	0.9974	48.534
2.1555	1.0469	48.570
2.2277	1.0867	48.512
2.2559	1.0946	48.529
2.2523	1.0939	48.569
		Mean, 48.543±.0077

The weighted mean of both series is nearly 48.540±.0030. Hence, Gd=157.24. Brauner's single determination may be neglected.

There are also two determinations made by Feit and Przibylla,[2] with their volumetric method:

Gd_2O_3.	O.	Atomic weight.
0.3852	0.05097	157.377
.3956	.05234	157.398
		Mean, 157.388±.0067

The three ratios for gadolinium are:

(1) $Gd_2(SO_4)_3.8H_2O : Gd_2O_3 :: 100 : 48.540 \pm .0030$
(2) $Gd_2(SO_4)_3 : Gd_2O_3 :: 100 : 60.070 \pm .0011$
(3) $O : Gd :: 16 : 157.388 \pm .0067$

Reducing these ratios with $S=32.065 \pm .00012$ and $H=1.0078 \pm .00001$ we have:

From ratio—	
2	Gd=156.673±.0059
1	157.256±.0154
3	157.388±.0067
General mean	Gd=157.008±.0044

[1] Compt. Rend., 140, 583. 1905.

[2] Zeitsch. anorg. Chem., 50, 260. 1906.

TERBIUM.

The older determinations of atomic weight made upon terbium preparations of doubtful character may well be ignored. Boisbaudran[1] has published two estimates of this constant. First, for two preparations, one with a lighter and one with a darker earth, he gives Tb = 161.4 and 163.1. In his second paper he makes Tb = 159.01 to 159.95; probably with $SO_3 = 80$. According to Feit[2] Tb = 158.6. Emma Potratz,[3] by various methods, found Tb = 154, approximately. For all of these determinations the essential details are lacking.

The series of determinations by Urbain[4] is more satisfactory. The octohydrated sulphate was converted into the anhydrous salt by careful heating, with the following results:

$Tb_2(SO_4)_3.8H_2O$.	$Tb_2(SO_4)_3$.	Per cent H_2O.
2.0407	1.6489	19.199
1.9626	1.5859	19.194
2.2580	1.8245	19.198
2.2385	1.8087	19.201
2.0037	1.6190	19.200
		Mean, 19.198 ± .0008

Hence, Tb = 159.205 ± .0130.

DYSPROSIUM.

The atomic weight of dysprosium was first determined by Urbain and Demenitroux.[5] They reduced the octohydrated sulphate to oxide, by calcination, with the following results, taking all their data as one series:

$Dy_2(SO_4)_3.8H_2D$.	Dy_2O_3.	Per cent Dy_2O_4.
1.6966	0.8359	49.269
2.0926	1.0301	49.226
1.8415	.9069	49.248
1.5519	.7649	49.288
2.4955	1.2296	49.273
1.8130	.8927	49.238
1.8817	.9271	49.269
1.1164	.5500	49.266
1.7308	.8528	49.272
2.6038	1.2820	49.236
1.6942	.8346	49.262
2.1776	1.0726	49.256
		Mean, 49.259 ± .0036

Hence, Dy = 162.547 ± .0190.

Engle and Balke[6] determined the atomic weight of dysprosium by the conversion of the oxide into the chloride. Their method has already been described under yttrium. The data, with vacuum weights, are as follows:

Dy_2O_3.	$DyCl_3$.	Ratio.
0.50996	0.73300	143.7367
1.05741	1.51998	143.7361
.65617	.94352	143.7920
1.22603	1.76297	143.7950
1.96935	2.83135	143.7707
		Mean, 143.7661 ± .0061

Hence, Dy = 164.23.

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[1] Compt. Rend., 102, 396, and 111, 474. 1886-1890.
[2] Zeitsch. anorg. Chem., 43, 280. 1905.
[3] Chem. News, 92, 3. 1905.
[4] Compt. Rend., 142, 957. Preliminary papers by Urbain are in C. R. 141, 521; *ibid.*, 142, 727; Bull. Soc. Chim. (3), 33, 403. See also Journ. Chim. Phys., 4, 321.
[5] Compt. Rend., 143, 598. 1906.
[6] Journ. Amer. Chem. Soc., 39, 67. 1917.

The same method was also followed by Kremers, Hopkins, and Balke,[1] whose data, with vacuum weights, are as follows:

Dy_2O_3.	$DyCl_3$.	Ratio.
0.72974	1.04979	143.859
1.36017	1.95604	143.808
.69716	1.00255	143.804
1.02493	1.47475	143.887
.87688	1.26253	143.979
.69318	.99677	143.796
1.55248	2.23374	143.882
.83958	1.20763	143.837
1.56481	2.25129	143.869
		Mean, 143.858±.0128

Hence Dy = 163.83.

Combining this series with that of Engle and Balke, the general mean is 143.782 ± .0056 The discordance between the two series of determinations indicates that the method is not satisfactory.

Kremers, Hopkins, and Engle also determined the ratio between silver and dysprosium chloride, with the following results:

$DyCl_3$.	Ag.	Ratio.
1.04979	1.26301	120.309
1.95604	2.35380	120.334
1.47475	1.77504	120.362
1.26253	1.51991	120.386
.99677	1.20033	120.421
2.23374	2.68806	120.338
1.20763	1.45325	120.339
2.25129	2.70992	120.371
		Mean, 120.358±.0084

Hence Dy = 162.517.

There are now three ratios from which to compute the atomic weight of dysprosium. Reducing them with Ag = 107.880 ± .00016, Cl = 35.4605 ± .00011, S = 32.0650 ± .00012, and H = 1.0078 ± .00001, we have—

From the silver ratio	Dy = 162.517 ± .0236
From the sulphate	162.547 ± .0190
From the oxide	164.162 ± .0236
General mean	Dy = 162.987 ± .0125

The oxide ratio, however, is untrustworthy. The other two ratios, which are in fair agreement, show that the atomic weight of dysprosium is somewhere near 162.5, which value may be for the present adopted.

HOLMIUM.

For the atomic weight of holmium there is a series of syntheses of the sulphate from the oxide by Holmberg.[2] The data are as follows:

Ho_2O_3.	$Ho_2(SO_4)_3$.	Per cent Ho_2O_3.
0.3467	0.5687	60.964
.3400	.5579	60.943
.3960	.6496	60.961
.7631	1.2524	60.930
.6877	1.1286	60.934
.5378	.8822	60.961
		Mean, 60.949±.0041

Hence Ho = 163.443 ± .0254.

[1] Journ. Amer. Chem. Soc., 40, 598. 1918.

[2] Zeitsch. anorg. Chem., 71, 226. 1911.

ERBIUM, THULIUM.

Since the earth which was formerly regarded as the oxide of erbium is now known to be a mixture of two or three different oxides the older determinations of its molecular weight have little more than historical interest. Nevertheless the work done by several investigators may properly be cited, if only for the sake of completeness.

First, Delafontaine's[1] early investigations may be considered. A sulphate, regarded as erbium sulphate, gave the following data. An oxalate was thrown down from it, which, upon ignition, gave oxide. The percentages in the fourth column refer to the anhydrous sulphate. In the last analysis water was not estimated, and I assume for its water the mean percentage of the four preceding experiments:

Sulphate.	Er_2O_3.	H_2O.	*Per cent* Er_2O_3.
0.827	0.353	0.177	54.308
1.0485	.4475	.226	54.407
.803	.3415	.171	54.035
1.232	.523	.264	54.028
1.1505	.495	...	54.760
			Mean, $\overline{54.308} \pm .0915$

Hence Er = 118.75.

Bahr and Bunsen[2] give a series of results, representing successive purifications of the earth which was studied. The final result, obtained by the conversion of oxide into sulphate, was as follows:

.7880 grm. oxide gave 1.2765 grm. sulphate. 61.653 per cent oxide.

Hence Er = 169.09.

Hoeglund,[3] following the method of Bahr and Bunsen, gives these figures:

Er_2O_3.	$Er_2(SO_4)_3$.	*Per cent* Er_2O_3.
1.8760	3.0360	61.792
1.7990	2.9100	61.821
2.8410	4.5935	61.848
1.2850	2.0775	61.853
1.1300	1.827	61.850
.8475	1.370	61.861
		Mean, $\overline{61.8375} \pm .0063$

Hence, Er = 170.60.

According to Thalén,[4] spectroscopic evidence shows that the "erbia" studied by Hoeglund was largely ytterbia.

Humpidge and Burney[5] give data as follows:

1.9596 grm. $Er_2(SO_4)_3$ gave 1.2147 grm. Er_2O_3. 61.987 per cent.
1.9011 " 1.1781 " 61.965 "
Mean, $\overline{61.976} \pm .0074$

Hence, Er = 171.75.

The foregoing data were all published before the composite nature of the supposed erbia was fully recognized. It will be seen, however, that three sets of results were fairly comparable, while Delafontaine evidently studied an earth widely different from that investigated by the others. Since the discovery of ytterbium, some light has been thrown on the matter. The old erbia is a mixture of several earths, to one of which, a rose-colored body, the name erbia is now restricted. For the atomic weight of the supposedly true erbium Cleve[6] gives three determinations, based on syntheses of the sulphate after the usual method. His weights were as follows, with the percentage ratio added:

Er_2O_3.	$Er_2(SO_4)_3$.	*Per cent* Er_2O_3.
1.0692	1.7436	61.321
1.2153	1.9820	61.317
.7850	1.2808	61.290
		Mean, $\overline{61.309} \pm .0068$

Hence, Er = 166.30.

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[1] Ann. Chem. Pharm., 134, 108. 1865.
[2] Ann. Chem. Pharm., 137, 21. 1866.
[3] K. Svensk. Vet. Akad. Handlingar, Bd. 1, No. 6.
[4] Wiedemann's Beiblätter, 5, 122. 1881.
[5] Journ. Chem. Soc., 35, 116. 1879.
[6] K. Svensk. Vet. Akad. Handlingar, No. 7. 1880.

The discussion over the complexity of erbia, however, did not stop with the work of Cleve. Krüss,[1] assisted by K. Hofmann, made a long series of fractionations of erbium material, and gave crude atomic weight determinations of them, which varied widely. The figures need not be reproduced here. L. Hermann[2] also has studied the subject, and states that the old erbia is separable into two earths, one giving red and the other yellow salts.

More recent determinations of the atomic weight of erbium are as follows. First, two unimportant analyses made by Brill[3] with the aid of the microbalance:

$Er_2(SO_4)_3$.	Er_2O_3.	Per cent Er_2O_3.
92.35	56.55	61.234
36.75	22.68	61.496
		Mean, 61.365±.0873

Hence, Er = 166.75.

Under the name "neo-erbium" Hofmann and Burger[4] describe carefully purified material, which gave a sharp and distinct spectrum. Four syntheses of the sulphate gave the subjoined figures:

Er_2O_3	$Er_2(SO_4)_3$.	Per cent Er_2O_3.
0.9048	1.4724	61.451
.4666	.7594	61.443
1.4181	2.3077	61.451
1.0789	1.7563	61.436
		Mean, 61.445±.0031

Hence, Er = 167.40.

Later determinations by Hofmann[5] involved both syntheses and analyses. The oxide was converted into sulphate, which was afterwards calcined to oxide again. The weights are as follows, giving six values for the percentage of oxide in the sulphate.

Er_2O_3	$Er_2(SO_4)_3$.	Er_2O_3.	Per cent Er_2O_3.
0.3117	0.5070	0.3117	61.481
.4486	.7296	.44863	61.481
.3718	.6048	.3718	61.486
			61.490
			61.475
			61.475
			Mean, 61.481±.0010

Hence, Er (neo-erbium) = 167.69.

Nearly all of the foregoing determinations can be neglected, as being of no present value. Three of them, however, may be combined as follows, giving the percentage of erbia in the sulphate:

Cleve	61.309±.0068
Hofmann and Burger	61.445±.0031
Hofmann	61.481±.0010
General mean	61.475±.0009

Hence, Er = 167.641 ± .0057. More data on "neo-erbium" are nedeed.

The atomic weight of thulium has not yet been carefully determined. Cleve[6] assigned to it the atomic weight 170.7, but without details as to weighings. According to Urbain,[7] the atomic weight is below 168.5.

ADDENDUM.

Since these computations were completed, additional work on erbium has been published by Wichers, Hopkins and Balke.[8] Their determinations were made by the oxide-chloride method, and gave values for Er ranging from 178.00 to 168.84. These values are too divergent to warrant further consideration. The method itself is defective, and the samples of erbium oxide were probably not free from other rare earths.

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[1] Zeitsch. anorg. Chem., 3, 353. 1893.
[2] Dissertation, Technische Hochschule, München, 1906.
[3] Zeitsch. anorg. Chem., 47, 464. 1905.
[4] Ber. Deutsch. Chem. Ges., 41, 308. 1908.
[5] Ber. Deutsch. Chem.Ges., 43, 2635. 1910.
[6] Compt. Rend., 91, 329. 1880.
[7] Compt. Rend., 145, 759. 1907. According to Auer von Welsbach (Anzeiger Wien. Akad., 45, 529, thulium is really complex. The atomic weight assigned to it has little significance.
[8] Journ. Amer. Chem.Soc., 40, 1615. 1918.

YTTERBIUM AND LUTECIUM.

Although ytterbium was long supposed to be a definite element, is has recently been shown to be complex, and its oxide is a mixture of at least two distinct earths. Nevertheless, the data relative to the atomic weight of the old ytterbium are worth assembling, if only for historical reference.

The first good series of determinations was by Nilson,[1] who effected the synthesis of the sulphate from the oxide in the usual manner. His figures are as follows:

Yb_2O_3.	$Yb_2(SO_4)_3$.	*Per cent* Yb_2O_3.
1.0063	1.6186	62.171
1.0139	1.6314	62.149
.8509	1.3690	62.155
.7371	1.1861	62.145
1.0005	1.6099	62.147
.8090	1.3022	62.126
1.0059	1.6189	62.134
		Mean, 62.147±.0036

Hence, Yb = 173.18.

Astrid Cleve,[2] by the same method, obtained the subjoined results:

Yb_2O_3.	$Yb_2(SO_4)_3$.	*Per cent* Yb_2O_3.
0.7791	1.2535	62.154
.5190	.8353	62.133
.4905	.7894	62.136
		Mean, 62.141±.0044

Hence, Yb = 173.13.

Brill,[3] who used the microbalance, gives the following figures:

$Yb_2(SO_4)_3$.	Yb_2O_3.	*Per cent* Yb_2O_3.
106.00	65.90	62.170
92.35	57.30	62.047
		Mean, 62.108±.0407

Hence, Yb = 172.85.

Brauner,[4] from 1.67279 grammes Yb_2O_3, obtained 2.69209 of $Yb_2(SO_4)_3$. Percentage Yb_2O_3, 62.137, and Yb = 173.10. There is also a preliminary note by G. and E. Urbain,[5] who found Yb = 172.6, but who give no details of the determination.

Feit and Przibylla,[6] by their volumetric method, obtained the following figures:

Yb_2O_3.	*O*.	*Atomic weight Yb*.
0.6424	0.07808	173.459
.6408	.07783	173.600
.6403	.07779	173.547
.6466	.07858	173.485
		Mean, 173.523±.0214

The complexity of the old ytterbium was proved almost simultaneously by Auer von Welsbach and Urbain.[7] Urbain, by a long series of fractionations, obtained from it two end products, one, *neo-ytterbium*, with an atomic weight near 170; the other, *lutecium*, approximately 174. Welsbach,[8] whose work was published a little later, proposed for his earths the names *aldebaranium* and *cassiopeium*, and gave more explicit figures as to their atomic weights. His data are as follows:

Ad_2O_3.	$Ad_2(SO_4)_3$.	*Per cent* Ad_2O_3.
0.4181	0.6730	62.125
.5984	.9634	62.113
.6173	.9939	62.109
		Mean, 62.116±.0011

[1] Compt. Rend., 91, 56. 1880. Ber. Deutsch. chem. Ges., 13, 1430.
[2] Zeitsch. anorg. Chem., 32, 129. 1902.
[3] Zeitsch. anorg. Chem., 47, 464. 1905.
[4] Abegg's Handbuch, 3 (1), 335.
[5] Compt. Rend., 132, 136.
[6] Zeitsch. anorg. Chem., 50, 261. 1906.
[7] Compt. Rend., 145, 759. 1907. 146, 406. 1908.
[8] Monats. Chem., 29, 192. 1908.

Hence, Ad = 172.92.

Cp_2O_3.	$Cp_2(SO_4)_3$.	Per cent Cp_2O_3.
0.3716	0.5967	62.276
.3086	.4956	62.268
.4026	.6465	62.274
		Mean, 62.273 ± .0017

Hence, Cp = 174.24.

In a later paper,[1] Welsbach gives additional determinations of the two atomic weights. In this case, however, he analyzed the octohydrated sulphates, with the following results:

Cassiopeium.

$Cp_2(SO_4)_3.8H_2O$.	Cp_2O_3.	Per cent Cp_2O_3.
2.0428	1.0394	50.881
2.0197	1.0274	50.869
2.4044	1.2232	50.873
		Mean, 50.874 ± .0024

Hence, Cp = 174.99.

Aldebaranium.

$Ad_2(SO_4)_3.8H_2O$.	Ad_2O_3.	Per cent Ad_2O_3.
2.0530	1.0392	50.619
2.0891	1.0575	50.620
2.1155	1.0710	50.631
		Mean, 50.623 ± .0027

Hence, Ad = 173.009.

A preliminary notice on the atomic weight of "neo-ytterbium," by Blumenfeld and Urbain,[2] gave merely the final result of the determination, but without details. These, however, have been sent me by Professor Urbain in a personal communication. They are as follows:

$Yb_2(SO_4)_3.8H_2O$.	Yb_2O_3.	Per cent Yb_2O_3.
0.40073	0.20311	50.685
.46594	.23621	50.695
.95456	.48388	50.691
.59774	.30292	50.678
.42429	.21502	50.678
1.07123	.54302	50.691
.48222	.24446	50.695
.59187	.30006	50.697
.65113	.33008	50.693
.89289	.45262	50.692
.47366	.24010	50.690
2.04620	1.03710	50.684
1.96940	.99840	50.696
		Mean, 50.690 ± .0012

Hence, Yb = 173.56.

None of these determinations can be regarded as final. Nor is it necessary to enter here into the controversy between Welsbach and Urbain relative to priority. In the matter of nomenclature alone, the priority of Urbain is clear.[3]

His name lutecium is therefore accepted, with Lu = 175. For the other component of the mixed earths the original name ytterbium would seem to be preferable to neoytterbium, and Yb = 173. These round numbers are perhaps as probable as any others which might be chosen.

THE HELIUM-ARGON GROUP.

The five inert gases, helium, neon, argon, krypton, and xenon, are apparently incapable of forming compounds. Their atomic weights, therefore, can only be inferred from their densities, for which the following data are available.

[1] Monats. Chem., 34, 1724. 1913.
[2] Compt. Rend., 159, 323. 1914.
[3] For a reclamation of priority, see Welsbach, Monatsh. Chem., 33, 695.

For helium the earliest determinations by Ramsay [1] are too high. He obtained values ranging from 3.89 to 4.84, and later figures above 2.13, when the density of oxygen as the standard is put at 16. Langlet,[2] a little later, assigned to helium the density 2.00 Ramsay and Travers,[3] after the discovery of neon, krypton, and xenon, with purer helium, found its density to be 1.98.

More recent determinations of the density of helium by Watson,[4] Heuse,[5] and Taylor [6] give the weight of the normal liter of helium as follows:

Two determinations by Watson give the weight as 0.17830 and 0.17814 gramme, whence He = 3.994.

Heuse gives seven determinations in mean 0.1785 gramme. This, reduced with the corresponding weight of oxygen, 1.4290 grammes, and from the measured compressibility of helium, gives He = 4.002.

Taylor, using a microbalance, and by direct comparison with oxygen and hydrogen, found He = 4.0008 ± .0005. Twelve determinations were made and reduced by means of the compressibility of helium. The atomic weight of helium then may be taken as He = 4, without serious danger of error. The older determinations give slightly lower values.

The density of argon has been carefully determined first by Ramsay [7] and by Rayleigh.[8]

Compared with an equal volume of oxygen weighing 2.62760 grammes, Rayleigh found for argon the following weights:

3.2710	3.2750
3.2617	3.2748
3.2727	3.2741
3.2652	

Rayleigh accepts the last three determinations, which give 3.27463 in mean. With O = 16, the density of argon becomes 19.9399 ± .0012.

Ramsay's figures, also referred to O = 16, are as follows:

19.904	19.959
19.823	19.969
19.816	19.932

Rejecting the second and third of these determinations the four remaining values give in mean a density of 19.941 ± .0099. Correcting the figures for argon by the method of limiting densities, D. Berthelot [9] assigns to argon the density 19.941.

Fischer and Haehnel [10] found for the density of argon as referred to O = 16 the following values:

19.93	19.95
19.94	19.94
19.95	19.98
19.97	
	Mean, 19.951

A year later Fischer and Froboese [11] purified argon by many fractionations and obtained 19.95 as their final value. Hence, A = 39.90. There is also a memoir by Schultze,[12] who determined the density of argon and from it found A = 39.945. Still more recently Leduc,[13] from measurements of the density and compressibility, finds A = 39.91. The average of all the values for argon is near A = 39.90.

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[1] Proc. Roy. Soc., 58, 81. 1895. Journ. Chem. Soc., 57, 684. 1895.
[2] Zeitsch. anorg. Chem., 10, 289. 1895.
[3] Proc. Roy. Soc., 67, 329. 1900. Phil. Trans., 197; A 47. 1900.
[4] Journ. Chem. Soc., 97, 810. 1910.
[5] Verhandl. Deutsch. physikal. Ges., 15, 518. 1913. Heuse also cites determinations by Olzewski, Schierloh, and Kamerlüngh-Onnes.
[6] Phys. Review, 10, 617. 1917.
[7] Phil. Trans., 186, 238. 1895.
[8] Proc. Roy. Soc., 59, 201. 1896.
[9] Compt. Rend., 126, 1501.
[10] Ber. Deutsch. Chem. Ges., 43, 1435. 1910.
[11] Ibid., 44, 92. 1911.
[12] Annalen d. Physik. (4) 48, 269. 1915.
[13] Compt. Rend., 167, 70. 1918.

The densities of three other inert gases were first determined by Ramsay and Travers.[1] Referred to O=16, the figures become

Ne	9.99	9.94
Kr	40.88	40.78
Xe	64.00	63.64

They also assign to argon the densities of 19.93 and 19.96.

More recent determinations of the density of neon are by Watson[2] and by Leduc.[3] For the weight of the normal liter, in grammes, Watson obtained the following values:

0.9002	0.8997
.9004	.8997
.9006	.9001
.9005	.9001
.9002	.9002
	.8998

The corrected mean is 0.9002. Hence, by the method of limiting densities, Watson found Ne=20.200.

According to Leduc the density of neon, referred to air as unity, is 0.695. Hence Ne=20.15, reduced by means of the compressibility of the gas.

Ladenburg and Krügel,[4] in their determinations of the density of krypton, obtained erroneous values, namely, 29.335 and 29.405. Ramsay,[5] in still later experiments, found for Kr the densities 40.81, 40.82, and 40.73, in agreement with the figures given by Ramsay and Travers.

More conclusive data for krypton and xenon are given by Moore,[6] who worked with residues separated by fractionation from 120 tons of liquid air. For krypton the densities found were 41.504 and 41.509, or 41.506 in mean. For xenon Moore found the densities 65.380 and 65.328, in mean, 65.354. Moore's figures have since been reduced by Watson[7] by the method of limiting densities. The values thus obtained for the two atomic weights are—

Kr= 82.92
Xe=130.22

For the gaseous emanation of radium, *niton*, Ramsay and Gray,[8] who weighed very minute quantities on a microbalance, found Nt=220. In a later paper Gray and Ramsay[9] report values ranging from 218 to 227. They regarded 222.4 as the most probable value. Debierne[10] by a different method found Nt=220. Theoretically, the true atomic weight of niton should be that of radium, 226, minus 4, the weight of one atom of helium—that is, Nt=222.

For ordinary uses the following values can be used for this group of elements:

He= 4.0	Kr= 82.9
Ne=20.2	Xe=130.2
A =39.9	Nt=222.0

[1] Proc. Roy. Soc., 67, 329. Phil. Trans., 197; A 47. 1900.
[2] Journ. Chem. Soc., 97, 810. 1900.
[3] Compt. Rend., 158, 864. 1914.
[4] Chem News, 81, 205. From Sitzungsb. Berlin Akad., 1900, 212.
[5] Proc. Roy. Soc., 71, 421. 1903.
[6] Journ. Chem. Soc., 93, 2181. 1908.
[7] Journ. Chem. Soc., 97, 833. 1910.
[8] Compt. Rend., 151, 126. 1910.
[9] Proc. Roy. Soc., 84 A, 536. 1911.
[10] Compt. Rend., 150, 1740. 1910.

TABLE OF ATOMIC WEIGHTS.

In the following table the results of the foregoing calculations are brought together, each atomic weight being rounded off to five significant figures, or sometimes fewer. For convenience the values are given in two columns, referring to the two ultimate standards, O = 16 and H = 1. Many chemists prefer the latter, and their wishes are, in a work like this, entitled to respectful consideration:

	O=16.	*H=1.*
Aluminum	27.039	26.830
Antimony	120.06	119.13
Argon	39.9	39.59
Arsenic	74.956	74.376
Barium	137.36	136.29
Bismuth	208.06	206.45
Boron	10.912	10.827
Bromine	79.923	79.304
Cadmium	112.38	111.51
Caesium	132.81	131.78
Calcium	40.090	39.700
Carbon	12.003	11.910
Cerium	140.21	139.12
Chlorine	35.460	35.186
Chromium	52.036	51.633
Cobalt	58.956	58.520
Columbium	93.277	92.555
Copper	63.561	63.069
Dysprosium	162.5	161.24
Erbium	167.6	166.3
Europium	152.07	150.89
Fluorine	19.011	18.864
Gadolinium	157.01	155.80
Gallium	70.10	69.54
Germanium	72.50	71.94
Glucinum	9.093	9.023
Gold	197.21	195.68
Helium	4.0	3.97
Holmium	163.4	162.13
Hydrogen	1.0078	1.0000
Indium	114.87	113.98
Iodine	126.93	125.95
Iridium	193.04	191.55
Iron	55.833	56.401
Krypton	82.9	82.3
Lanthanum	138.80	137.73
Lead	207.10	205.50
Lithium	6.937	6.883
Lutecium	175.0	173.65
Magnesium	24.296	24.108
Manganese	54.949	54.524
Mercury	200.60	199.05
Molybdenum	96.03	95.29
Neodymium	144.24	143.12
Neon	20.2	20.05
Nickel	58.676	58.222
Niton	222.0	220.3
Nitrogen	14.008	13.900
Osmium	191.07	189.59
Oxygen	16.000	15.876
Palladium	106.66	105.83
Phosphorus	31.011	30.771
Platinum	195.21	193.70
Potassium	39.097	38.795
Praseodymium	140.88	139.79
Radium	225.95	224.20
Rhodium	102.93	102.13
Rubidium	85.434	84.773
Ruthenium	101.65	100.86
Samarium	150.40	149.29
Scandium	45.1	44.7
Selenium	79.168	78.555
Silicon	28.255	28.036
Silver	107.88	107.05
Sodium	23.003	22.825
Strontium	87.631	86.953
Sulphur	32.065	31.817
Tantalum	181.3	179.9
Tellurium	127.53	126.54
Terbium	159.20	157.97
Thallium	204.03	202.45
Thorium	232.19	230.39
Thulium	168.5	167.2
Tin	118.71	117.79
Titanium	48.099	47.727
Tungsten	184.10	182.67
Uranium	238.15	236.31
Vanadium	50.947	50.553
Xenon	130.2	129.2
Ytterbium	173.0	171.66
Yttrium	89.33	88.66
Zinc	65.397	64.891
Zirconium	91.17	90.464

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